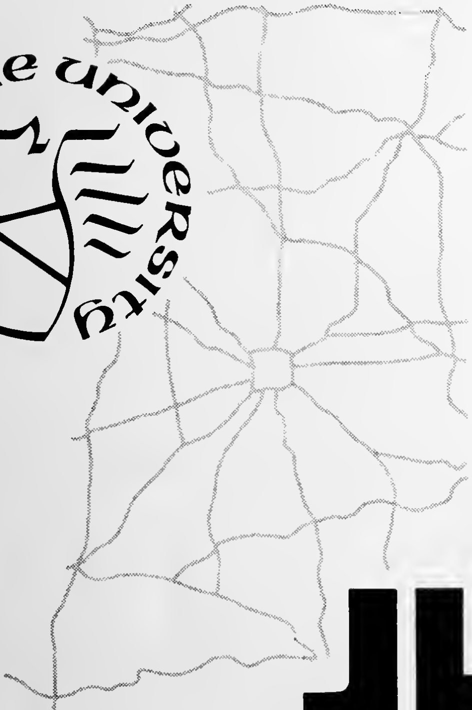
COMBINATION TREATMENTS FOR CONTROL OF WILD GARLIC AND COMMON MILKWEED

OCTOBER 1970 - NUMBER 22



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Progress Report

COMBINATION TREATMENTS FOR CONTROL OF WILD GARLIC AND COMMON MILKWEED

TO: J. F. McLaughlin, Director
Joint Highway Research Project

October 28, 1970

File: 9-5-3

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-48C

The attached research report "Combination Treatments for Control of Wild Garlic and Common Milkweed" is a Progress Report on the HPR-1 (8) project "Research in Roadside Development." This report is on Part III "Chemical Weed Control." It has been authored by Messrs. D. James Morre, R. D. Cheetham, Stanislaw Krawiec and J. D. Clark. The research was conducted in the Department of Botany and Plant Pathology of the School of Agriculture.

The report is presented to the Board as information and for acceptance as partial fulfillment of the objectives of this project. The report will also be forwarded to the ISHC and the FHWA for review, comment and acceptance as partial fulfillment of the objectives of the research.

Respectfully submitted,

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COMBINATION TREATMENTS FOR CONTROL OF WILD GARLIC AND COMMON MILKWEED

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Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

Purdue University

Lafayette, Indiana

September 15, 1970

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Two abundant roadside species, Common Milkweed (Asclepias syriaca) and Wild Garlic (Allium vineale) are not economically controlled by any one chemical or cultural treatment presently available. Both species resist mowing as a control measure. Common Milkweed is particularly unsightly and seems to be most prevalent at intersections where the plants may become sufficiently tall to obstruct vision. Both species are potential invaders of adjacent crop land.

In the present study, a potent new herbicide providing control of a broad spectrum of plant species was selected for initial use in combinations with the standard roadside herbicides 2,4-D and 2,4,5-T. The material selected was picloram (4-amino-3,5,6-trichloropicolinic acid) (17,20) which is sold commercially as Tordon Herbicide (Trademark of the Dow Chemical Company, Midland, Michigan). The potential of combining Tordon + 2,4-D with dimethylsulfoxiide (DMSO), a potent herbicide solvent (20,21), was also explored. By acting as an adjuvant, DMSO afforded an opportunity for synergistic interaction (20,21) which we felt might prove helpful against spot infestations of especially difficult to control species such as Wild Garlic.

In the first part of this report, we describe field and greenhouse studies carried out over a period of 4 years in which an effective control measure for Wild Garlic was developed. Initially, 2,4-D, Tordon, 2,4,5-T and Dicamba alone and in combination were tested with either water or DMSO as the solvent. Tolerance of plants to herbicides formulated in DMSO seemed to be related to the cuticularized surface layers of the leaves and to heavy wax deposits (20). For this reason,

herbicide treatments were combined with measures designed to reduce wax deposits on leaves.

In the second part of this report, we describe laboratory, greenhouse and field studies leading to development of a combination herbicide for eradication of Common Milkweed. Greenhouse studies showed Tordon or Tordon + 2,4-D combinations to be effective herbicides for control of Common Milkweed. To reduce treatment costs, laboratory and greenhouse studies were initiated to determine what percentage of the Tordon could be replaced by either 2,4-D or 2,4,5-T without reducing overall herbicidal effectiveness. Timing of treatments was determined in the field. Application of Tordon- + 2,4-D or Tordon + 2,4,5-T combination herbicides in appropriate ratios at the late bloom stage of growth resulted in control of not only the above ground portions of the milkweed plants but also killed the extensive system of below ground rhizomes thereby preventing regrowth.

II. WILD GARLIC

INTRODUCTION

Wild garlic (Allium vineale L) is a serious problem both as a roadside weed which resists chemical and cultural treatments and as a potential invader of adjacent crop land. Wild garlic is particularily undesirable because it contains allyl sulfide which gives milk, small grains and meat products a characteristic onion flavor. Estimates of the annual damage caused by this taint run into millions of dollars (7). In Delaware, wild garlic has been reported to cause greater monetary loss than any other weed (3).

Early attempts to eradicate this weed involved plowing to keep winter growth under control followed by planting to an intertilled crop for several successive seasons (22). Mowing alone is ineffective (19). Control is made difficult due to the various methods of propagation available to this plant: aerial bulblets with fall germination, soft shelled below ground bulbs with fall germination, hard shelled below ground bulbs with late fall or early spring germination over a 1-3 year period and seeds with variable period of germination (6,7).

Chemical control has been largely unsuccessful and generally involved heavy spot treatments (7,14-16). Klingman (14) reported that a combination of mowing during the winter months and a March spray of 1 lb/acre of 2,4-D gave fair control. Repeated treatments with 2,4-D generally gave above ground kill (15,23) but the dosage required was high. Heavy spot treatments with 2,3,6-TBA were better than with 2,4-D but did not kill the dormant bulbs.(7). All reports emphasized that no single herbicide selectively eradicated wild garlic and that continuous

treatments over 2 to 6 years were necessary for eradication (7,14-16, 23).

To control wild garlic with chemicals an economically feasible method must be found to get the herbicide to the below ground bulbs. In the present study, a new herbicide (Tordon or picloram) was tested alone and in combination with 2,4-D. Treatments were designed to enhance the uptake and hopefully the translocation of the herbicides to the system of underground bulblets.

SPECIFIC PROCEDURES AND RESULTS

1967 Field Trials

Field trials were initiated in the spring of 1967 to test 2,4-D-Tordon-DMSO mixtures for control of spot infestations of wild garlic. Test plots were established in 5 locations in Indiana and Missouri on roadside rights-of-way during April and May. 2,4-D and Tordon (½ to 2 lb/A) were applied in water or DMSO (30 gpa) and in various combinations. A treatment consisting of 1 lb. 2,4-D + 1 lb. Tordon in 30 gal DSMO/A was most effective in killing top growth, surpassing 2 lb/A of either 2,4-D or Tordon alone in DMSO as well as the combination applied in water. Treatments applied early in the spring were more effective than those applied later in the season. Regrowth was determined in 1968 and in 1969 for the Indiana plots. Visual observations suggested that considerable regrowth resulted from secondary bulblets and that control of primary bulblets was not satisfactory. Differences between 2,4-D and Tordon or between application in water or DMSO were marginal on the basis of regrowth. Bulbs were not examined. The details of these studies were the subject of Quarterly Progress Reports for periods ending June 30, 1967; June 30, 1968 and December 31, 1969 and will not be repeated here.

1968 Greenhouse Studies

Greenhouse investigations during 1968 compared untreated controls with plants treated with 20 gpa of pure DMSO or 2,4-D, 2,4,5-T or Tordon (1/8 to 2 lb/A) in pure DMSO (20 gpa) or water (100 gpa). Onion (Allium sepa) plants were grown from seed in 11 cm (16 oz) plastic pots, 30 per pot, and thinned to 10 plants per pot. Three weeks later, treatments were applied using a platform sprayer at 10 psi. All herbicides were commercial formulations employing the amine-salts of 2,4-D and 2,4,5-T and the sodium salt of Tordon.

Response of onion to all herbicides was proportional to rate of application with maximum effectiveness being achieved at about 1 lb/A (Table 1, Figs. 1-6). In these experiments, 2,4-D was consistently the most effective herbicide but was followed closely by 2,4,5-T and Tordon with Tordon being least effective at all rates. Herbicidal effectiveness was greatly enhanced by application in DMSO especially at the lower treatment rates. At a rate of ½ lb/A 2,4-D, onion fresh weight was reduced by only 20% 3 weeks after treatment (Table 1) with the production of normal appearing bulbs (Fig. 1). Application of the 2,4-D in DMSO resulted in a 95% inhibition of fresh weight over the same time interval and complete suppression of bulbing (Fig. 1). Vigor of the few remaining plants was reduced, the root systems were undeveloped and it is questionable whether these seedlings would have survived in the field. Similar results with DMSO-2,4-D interactions with onion were observed in 1966 and 1967 greenhouse trials reported previously (20).

Table 1. Effects of DMSO (20 gpa) and varying rates of 2,4-D, 2,4,5-T and Tordon on growth of onion (<u>Allium</u> <u>sepa</u>) 3 weeks after treatment under greenhouse conditions. Seeds were planted 30/16 oz plastic pot and subsequently thinned to 10 plants/pot. Seeds were planted April 20, 1968 and treatments were applied May 24, 1968 at 10 psi. Each treatment was replicated 5 times.

Herbicide	Rate, lb/A	Solvent	Rate, gpa	Weight/10 plants, grams ± Standard deviation
None	-	Water	100	6.6 ± 0.7
	-	DMSO	20	5.9 ± 1.5
2,4-D	1/8	Water	100	6.8 ± 0.6
		DSMO	20	3.1 ± 0.6
	1/4	Water	100	4.7 ± 0.3
		DMSO	20	2.2 ± 0.9
	1/2	Water	100	4.3 ± 0.7
		DMSO	20	1.7 ± 0.7
	1	Water	100	3.1 ± 0.6
		DMSO	20	0.5 ± 0.2
	2	Water	100	1.2 ± 0.2
		DMSO	20	0.3 ± 0.1
2,4,5-T	1/8	Water	100	5.5 ± 1.0
		DMSO	20	3.6 ± 1.6
	1/4	Water	100	6.0 ± 0.5
		DMSO	20	4.5 ± 0.9
	1/2	Water	100	6.6 ± 1.2
		DMSO	20	2.8 ± 1.1
	1	Water	100	3.1 ± 1.0
		DMSO	20	1.1 ± 0.5
	2	Water	100	2.9 ± 1.1
		DMSO	20	1.0 ± 0.3
Tordon	1/8	Water	100	7.2 ± 3.0
		DMSO	20	4.1 ± 1.2
	1/4	Water	100	8.1 ± 2.6
		DMSO	20	3.7 ± 1.0
	1/2	Water	100	4.6 ± 0.6
		DMSO	20	2.7 ± 0.7
	1	Water	100	4.6 ± 0.7
		DMSO	20	2.9 ± 1.2
	2	Water	100	4.9 ± 0.6
		DMSO	20	2.7 ± 1.3

Fig. 1

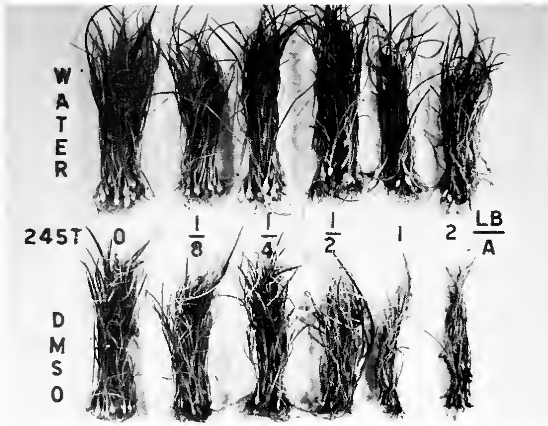


Fig. 2

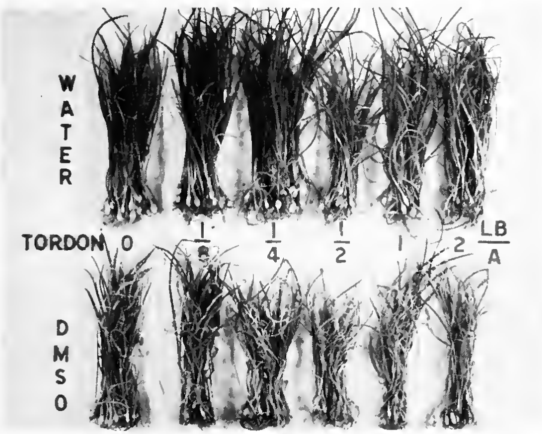


Fig. 3

Figures 1-3. Effects of DMSO (20 gpa) and varying rates of 2,4-D (Fig. 1), 2,4,5-T (Fig. 2) and Tordon (Fig. 3) on growth of onion (Allium sepa) under greenhouse conditions. Seeds were planted in 16 oz plastic pots, 30/pot. Seeds were planted April 20, 1968 and treatments were applied May 24, 1968 at 10 psi. Each treatment was replicated 5 times. Plants were photographed 3 weeks after treatment.

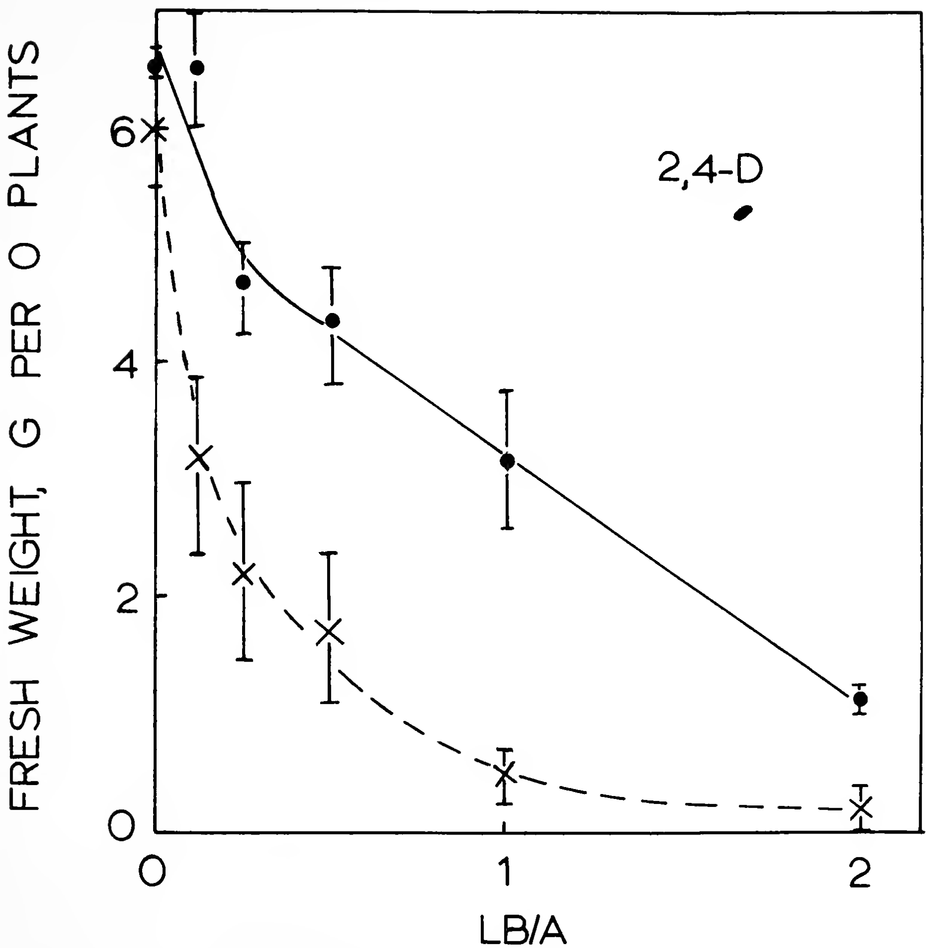


Figure 4. Effects of varying concentrations of 2,4-D (0, 1/8, 1/4, 1/2, 1 and 2 lb/A) applied in water or DMSO (100 gpa) on growth of onion (Allium sepa) under greenhouse conditions.

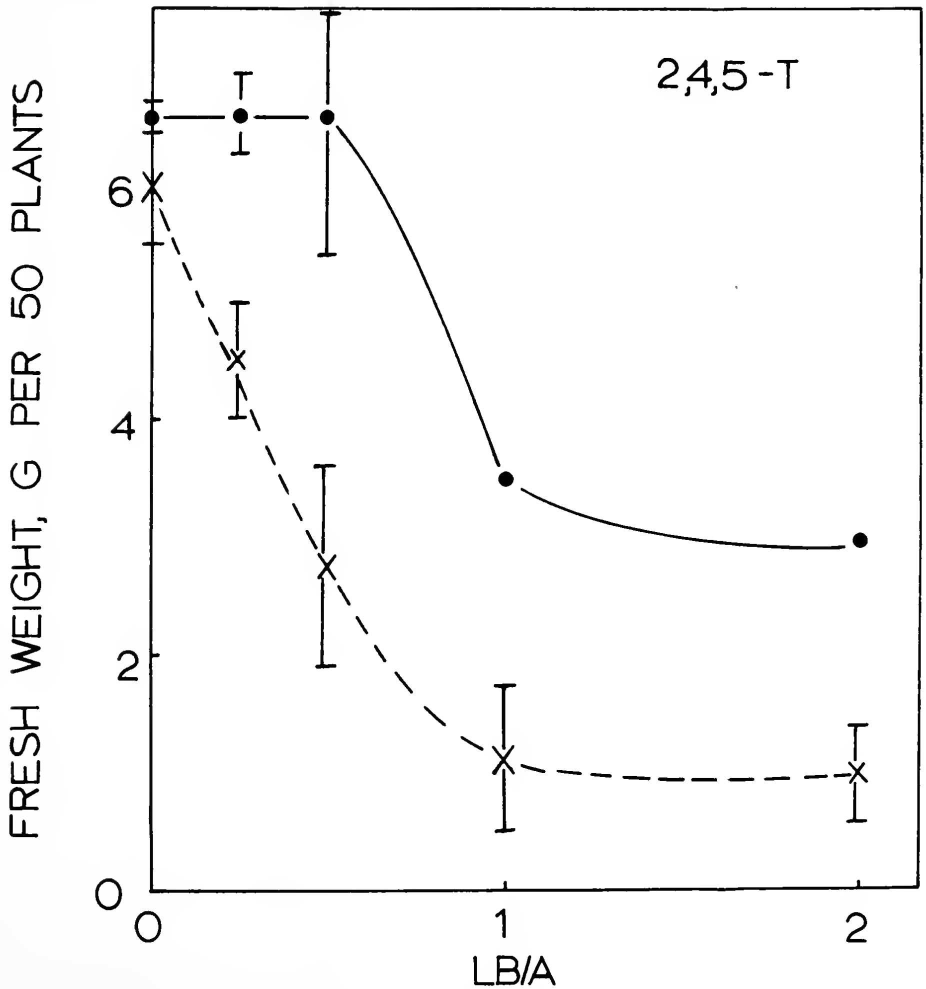


Figure 5. Effects of varying concentrations of 2,4,5-T (0, 1/8, 1/4, 1 and 2 lb/A) applied in water or DMSO (100 gpa) on growth of onion (<u>Allium sepa</u>) under greenhouse conditions.

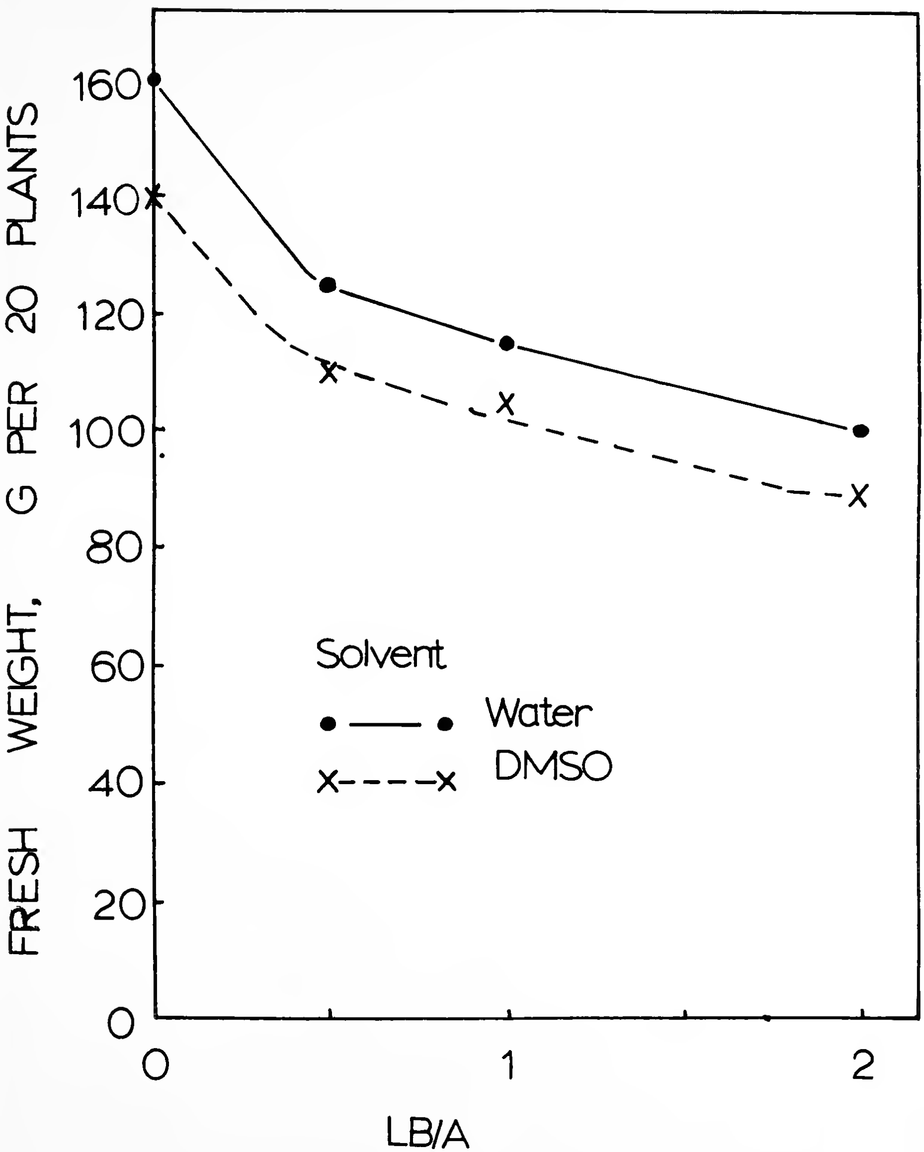


Figure 6. Effects of varying concentrations of Tordon (0, 1/8, 1/4, 1 and 2 lb/A) applied in water or DMSO (100 gpa) on growth of onion (Allium sepa) under greenhouse conditions.

Although results with 2,4-D were most dramatic (Fig. 1), similar enhancements of herbicidal toxicity by DMSO on onion were observed with 2,4,5-T (Fig. 2) and Tordon (Fig. 3). Unlike 2,4-D and 2,4,5-T, where maximum treatment effectiveness was at 1 lb/A, Tordon reach maximum effectiveness at ½ lb/A but plants were about twice as large as in the 2,4-D treatments and much less effected by the herbicide (Table 1). These results may reflect the more prolonged killing action of Tordon shown for bean plants (Fig. 40 of part II, Milkweed). More important, Tordon was ineffective in retarding bulb development. These observations may well explain the 1967 field results where Tordon gave most effective control of top growth but where regrowth was comparable to or greater than that of other treatments. Because of its similarity to 2,4-D, 2,4,5-T was replaced by Dicamba in the 1968 Field Trials but Tordon was retained to permit evaluation under field conditions.

1968 Field Trials

A second series of field trials was initiated in Washington County, Indiana in April 1968 in a roadside situation. A total of 22 treatments with 5 replications was included to compare Tordon, 2,4-D and Dicamba alone and in combinations with DMSO or water as the solvent. Plots were 5' x 10' with treatments applied April 25, 1968 at 30 gpa, 30 psi using a CO_2-powered hand sprayer. Treatment effectiveness was evaluated initially on May 15, 1968 and fresh weight was determined from a random sample of 20 plant tops/plot. Regrowth was determined visually in subsequent seasons.

The plants in these studies were approximately 12 inches tall at the time of treatment and observations in 1969-70 confirm the results obtained here that the plants were too large for best control of Wild Garlic. In general, results with Dicamba were comparable to those obtained for 2,4-D and earlier for 2,4,5-T suggesting that these three materials are roughly equivalent in their effectiveness for control of Wild Garlic (Table 2). As in 1967, the Tordon-2,4-D combination was most effective in control of top growth but not significantly different from either material alone although the results suggest an enhancement of Tordon activity by the addition of 1 part 2,4-D to 3 parts Tordon as compared to Tordon alone (Table 2). The relative effectiveness of 2,4-D and Tordon shown in Figures 7 and 8 confirm the previous greenhouse studies. Regrowth observations once again suggested no particular advantage of Tordon, 2,4,5-T or Dicamba over 2,4-D as a herbicide for Wild Garlic control. Further testing was restricted to the less costly material, 2,4-D.

Table 2. Comparison of Tordon, 2.4-D and Dicamba alone and in combinations at various rates with DMSO or water as the solvent (30 gpa). Roadside situation in Washington County, Indiana with treatments applied April 25, 1968 at the 12 inch stage of growth. Evaluations were on May 15, 1968.

Treatment, lb/A	Solvent	Weight (g)/20 plant tops ± Standard Deviation
0.75 Tordon + 0.25 2,4-D	Water	125 ± 5
	DMSO	110 ± 12
1.5 Tordon + 0.5 2,4-D	Water	114 ± 14
	DMSO	104 ± 10
3.0 Tordon + 1.0 2,4-D	Water	100 ± 8
	DMSO	88 ± 13
3.0 Tordon + 1.0 Dicamba	Water	97 ± 11
	DMSO	100 ± 20
1.0 2,4-D	Water	112 ± 10
	DMSO	103 ± 6
1.0 Dicamba	Water	115 ± 7
	DMSO	109 ± 7
3.0 Tordon	Water	103 ± 13
	DMSO	113 ± 11
4.0 2,4-D	Water	105 ± 18
	DMSO	85 ± 13
4.0 Dicamba	Water	103 ± 13
	DMSO	96 ± 17
4.0 Tordon	Water	119 ± 19
	DMSO	106 ± 13
None	Water	159 ± 30
	DMSO	139 ± 19

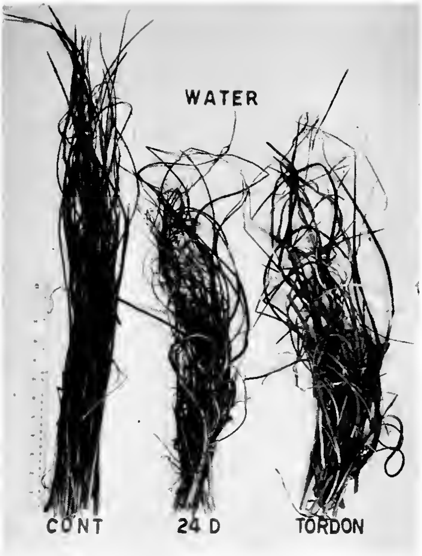


Fig. 7

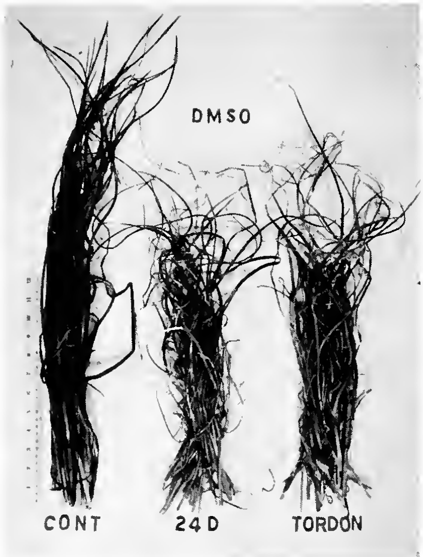


Fig. 8

Figures 7-8. Effects of 4 lb/A 2,4-D or Tordon applied under field conditions in water (Fig. 7) or DMSO (Fig. 8) as the solvent (30 gpa). Roadside situation in Washington County, Indiana with treatments applied Apıil 25, 1968 at the 12-inch stage of growth. Evaluations were on May 15, 1968.

The results with DMSO were uniformly disappointing in the field. Having been remarkably effective in greenhouse studies, DMSO caused no significant reduction in shoot growth in the field. The small average reduction of about 10 grams/20 plants (Table 3) seemed due to a non-specific solvent toxicity and no DMSO-herbicide interaction was detected (Table 4). Because of these results, 1969-1970 greenhouse testing emphasized the development of new approaches to wild garlic control and further testing was delayed until 1970.

Table 3. A comparison of 2,4-D, Dicamba and Tordon (4 lb/A) on the control of Wild Garlic (*Allium vineale*), Washington County, Indiana 3 weeks after treatment. Treatments applied April 25, 196[illegible] when the plants were 12 inches high in either water or DMSO (30 gpa).

Herbicide	Solvent	Fresh weight/20 plants, grams
None	Water	155
	DMSO	139
2,4-D	Water	105
	DMSO	95
Dicamba	Water	109
	DMSO	96
Tordon	Water	115
	DMSO	106

Table 4. Test for synergism between Tordon and 2,4-D and between Tordon and Dicamba in mixtures on the control of Wild Garlic (Allium vineale), Washington County, Indiana. Treatments applied April 25, 1968 when the plants were 12 inches high in either water or DMSO (30 gpa). Plant harvested 3 weeks after treatment.

Rate, lb/A Tordon	2,4-D	Dicamba	Solvent	Fresh weight/20 plants, grams
0	0	0	Water	159
			DMSO	139
3	1	0	Water	100
			DMSO	88
3	0	0	Water	103
			DMSO	113
0	1	0	Water	112
			DMSO	103
3	0	1	Water	97
			DMSO	100
0	0	1	Water	115
			DMSO	109

1969-70 Greenhouse Studies

Greenhouse investigations during 1969-70 sought new herbicide treatment combinations for control of wild garlic. Laboratory and greenhouse studies during 1969 to be reported on at a later date suggested that cuticle development in the field might explain the inconsistent results with DMSO as the solvent and ways were sought to reduce cuticle development. One treatment found effective was p-chloroisopropylphenylcarbamate (CIPC). Testing of CIPC-2,4-D-DMSO combination treatments was intensified in the spring of 1970 and these results are reported in detail.

Wild garlic: Rate of CIPC and cuticle development.-- Garlic plants were collected from the field near Lafayette, Indiana on 5 March 1970 when the plants were approximately 4.5 inches high. CIPC treatments were applied on March 12 at the 5 inch stage of growth just as the plants were recovering from the shock of being transplanted and beginning to grow at a constant rate (Figs. 9 and 10). To determine the amount of cuticular wax reduction, a quantitative analysis of surface wax was made by washing the surface of the leaves with petrolium ether according to the method of Gentner (11). The wash solution was placed in weighing containers, dried and weighed to constant weight at room temperature.

In control plants, wax remained approximately constant at 0.018 mg/plant (Fig. 11) suggesting that considerable cuticle thinning occurred in the greenhouse since the plants were growing at a constant rate. This confirmed earlier observations on reduced cuticle of greenhouse-grown plants (20). After 2 inches of growth, 2 lb/A of CIPC caused a reduction of about 30% in amount of wax/plant with the 1/2 and 1 lb/A

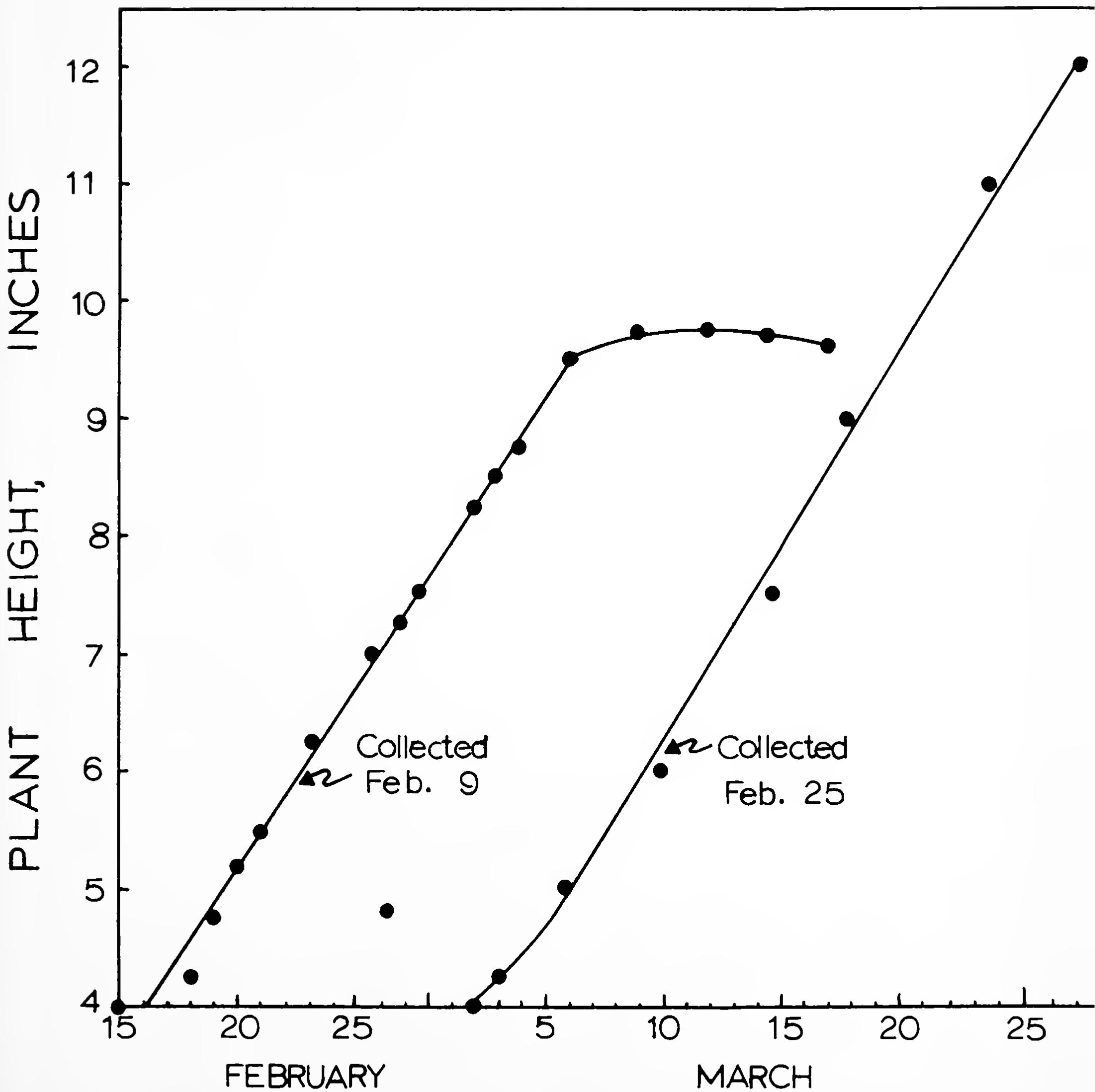
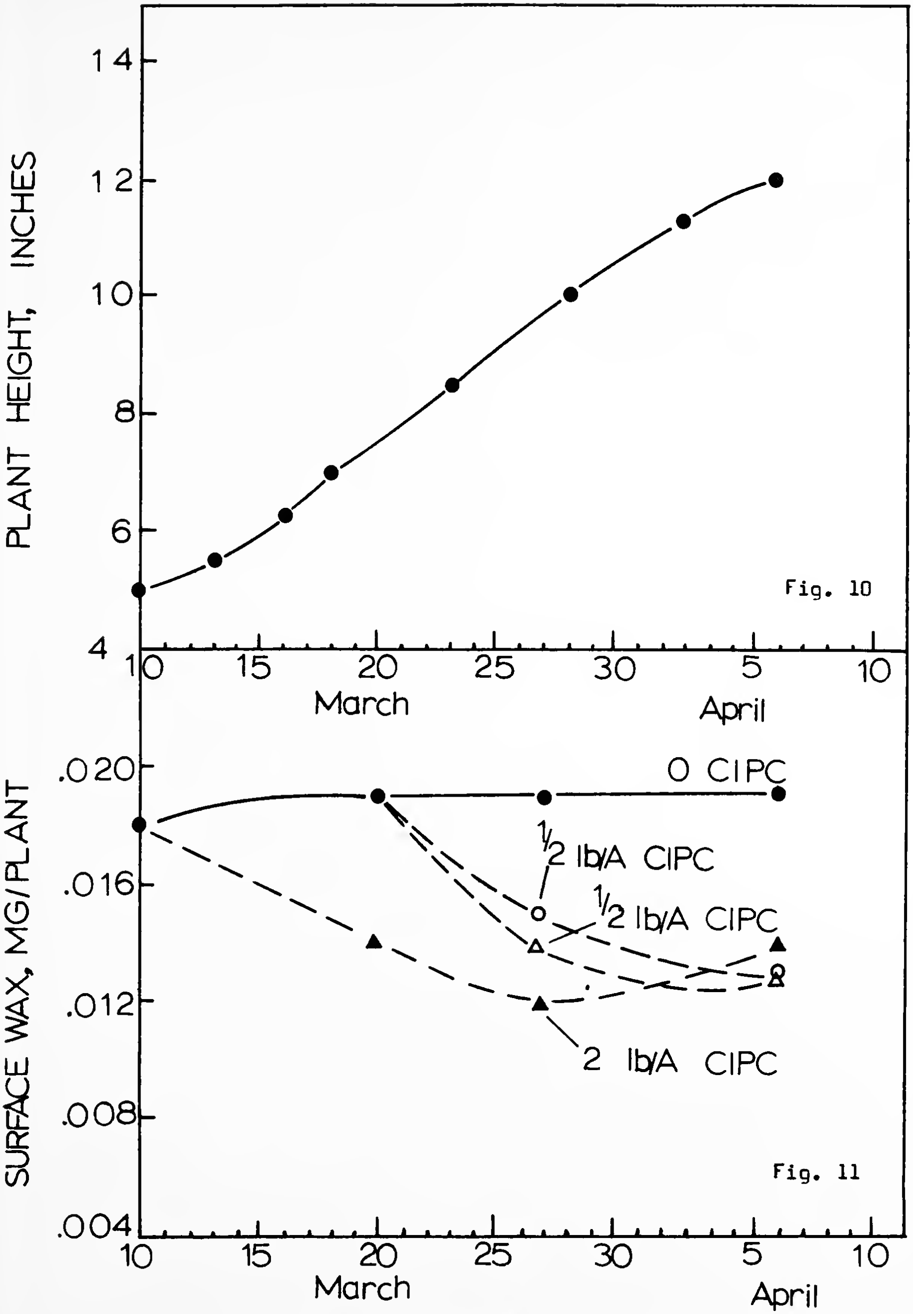


Figure 9. Growth of Wild Garlic plants in the greenhouse. Plants were collected in the field on the dates indicated and transplanted into pots for measurement and observation.



Figures 10-11. Effect of CIPC on growth (Fig. 10) and development of surface wax on leaves (Fig. 11) of Wild Garlic in the greenhouse. Upper Curve (Fig. 10) - Growth. Lower Curve (Fig. 11) - Wax/plant at 0, 1/2, 1 and 2 lb/A CIPC applied March 10.

rates showing a similar reduction after 4 inches of growth (Fig. 11). After 6 inches of growth all rates of CIPC were comparable giving about 40% reduction in surface wax (Fig. 11). A stimulation of growth of Wild Garlic by CIPC was also indicated (Table 5).

Wild Garlic: Rate of CIPC and plant height.-- Garlic plants were collected from the field near Lafayette, Indiana on February 9, 1970 when the plants were approximately 4 inches high and potted in 6 inch pots in the greenhouse. They were treated with varying rates of CIPC in 40 gpa water on Feb. 24, 1970 at a height of about 6.5 inches. 2,4-D (1 lb/A in pure DMSO (40 gpa) was applied at the 6, 8 and 10 inch stages of growth on February 25, March 4 and March 10 respectively. Visual observations of top kill were made at biweekly intervals. On May 28, the bulbs were removed from the pots for examination.

Examination of rate of top kill (Table 6) suggested that the 1/2 and 1 lb rates of CIPC significantly enhanced the killing action of 2,4-D applied in DMSO but that some antagonism was encountered at the 2 lb rate of CIPC. CIPC alone appeared to have no detrimental effect on growth of wild garlic. If anything, the treatments appeared to stimulate growth (see Table 5).

All 2,4-D treatments significantly reduced bulb development irrespective of CIPC pretreatment with greatest effectiveness encountered at the earliest times of treatment (6 and 8 inch stages of growth) (Table 7 and 8, Fig. 12). A reproducible enhancement of 2,4-D action by CIPC in terms of bulb development was noted only at the 10 inch growth stage where only partial control was given by any of the treatments (Table 6). It is of interest to note that all 2,4-D treated plants produced predominantly soft, white bulbs in contrast to the hard, brown

Table 5. Effect of CIPC (average of all treatment rates) on growth of wild garlic plants in the greenhouse as percent of control. Treatments were applied March 12, 1970.

Date of measurement	Fresh weight/plant (%of control)
March 20, 1970	92 ± 5
March 27, 1970	121 ± 14
April 7, 1970	114 ± 14

Table 6. Days to 100% kill of top growth of greenhouse-grown Wild Garlic plants treated with 2,4-D + DMSO at varying times following pretreatment with 0, ½, 1 or 2 lb/A CIPC at the 6-inch stage of growth.

1 lb 2,4-D + 40 gal DMSO/A applied at:	CIPC in water applied at 6-inch stage of growth			
	0	½	1	2 lb/A
6-inch stage	38	-	-	-
8-inch stage	30	20	20	24
10-inch stage	30	24	24	30

Table 7. Effect of CIPC pretreatment and subsequent 2,4-D (1 lb/A) in 40 gpa DMSO treatment on development of Wild Garlic bulbs in the greenhouse. Data collected 3½ months after beginning of treatments. Plants were collected from the field February 9, 1970 and grown and treated in the greenhouse.

				Bulbs/pot		
Pretreatment	Height	Treatment	Height	Number	Wt. (g)	Wt./Bulb
None	-	None	-	10	2.67	0.27
		2,4-D +DMSO	6-inch	1	0.05	0.05
			8-inch	0	0	0.00
			10-inch	16	1.38	0.09
CIPC, ½ lb/A	6-inch	None	-	7	1.55	0.22
		2,4-D + DMSO	8-inch	5	0.32	0.06
			10-inch	0	0	0.00
CIPC, 1 lb/A	6-inch	None	-	15	3.09	0.21
		2,4-D + DMSO	8-inch	3	0.18	0.06
			10-inch	18	0.81	0.05
CIPC, 2 lb/A	6-inch	None	-	19	5.98	0.31
		2,4-D + DMSO	8-inch	2	0.07	0.04
			10-inch	10	0.32	0.03

Table 8. Effect of CIPC pretreatment and subsequent 2,4-D (1 lb/A) in DMSO (40 gpa) treatment on development of Wild Garlic bulbs in the greenhouse. Data collected 3½ months after beginning of treatment. Plants were collected from the field on February 9, 1970 and treated and grown in the greenhouse.

				Primary Bulbs*			Secondary bulbs*			
Pretreatment	Height	Treatment	Height	No/pot	Wt	Wt/bulb	No/pot	Wt	Wt/bulb	Soft
None	-	None	-	5	2.40	0.48	5	0.30	0.06	0/5
		2,4-D + DMSO	6-inch	0	0	0	1	0.05	0.05	0/1
			8-inch	0	0	0	0	0	0	-
			10-inch	2**	0.50	0.25	14	0.88	0.06	5/14
CIPC, ½ lb/A	6-inch	None	-	2	0.62	0.31	5	0.93	0.18	0/5
		2,4-D + DMSO	8-inch	0	0	0	5	0.32	0.06	2/5
			10-inch	0	0	0	0	0	0	-
CIPC, 1 lb/A	6-inch	None	-	4	1.77	0.44	11	1.32	0.12	0/11
		2,4-D + DMSO	8-inch	0	0	0	3	0.18	0.06	3/3
			10-inch	1**	0.16	0.16	17	0.65	0.04	15/17
CIPC, 2 lb/A	6-inch	None	-	7	4.93	0.70	12	1.05	0.09	0/12
		2,4-D + DMSO	8-inch	0	0	0	2	0.07	0.04	1/2
			10-inch	1**	0.14	0.14	9	0.28	0.03	8/9

* Weights are in grams

** Primary bulbs white and soft

bulbs characteristic of untreated plants and plants receiving CIPC alone (Fig. 12, Tables 7 and 8). These bulbs showed a tendency to germinate prematurely and rot easily. In general, we were encouraged by these results and further tests were run to verify their generality.

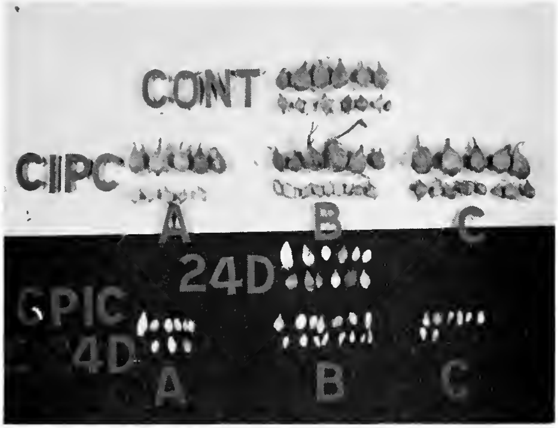


Figure 12. Effect of CIPC applied at the 6-inch stage of growth with or without 1 lb/A 2,4-D + 40 gpa DMSO at the 10-inch stage of growth on bulb development of Wild Garlic in the greenhouse. A - $\frac{1}{2}$ lb/A CIPC. B - 1 lb/A CIPC. C - 2 lb/A CIPC. 2,4-D - No CIPC. CONT - No CIPC and no 2,4-D. Evaluations were $3\frac{1}{2}$ months after beginning of treatments. Photographed at the same reduction at Fig. 13.

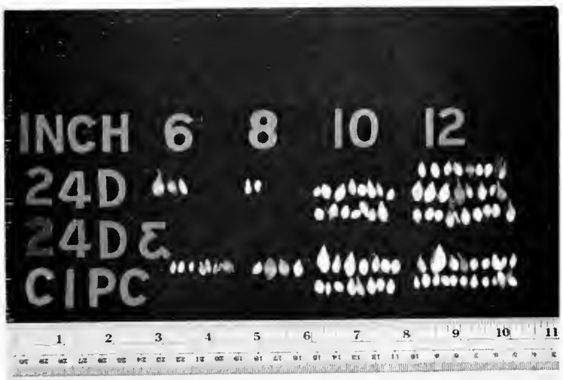


Figure 13. Effect of 2,4-D (1 lb/A) applied in DMSO (40 gpa) at various stages of growth (height in inches) with and without pretreatment with 1 lb/A of CIPC in water (40 gpa) at the 4-inch stage of development on bulb development of Wild Garlic in the greenhouse. Evaluations were 3 months after the beginning of treatment.

Wild garlic: Stage of treatment with and without CIPC. - Garlic plants were collected from the field near Lafayette, Indiana of February 25, 1970 when the plants were approximately 4 inches high and potted in 6 inch pots in the greenhouse. They were treated with 1 lb/A CIPC in 40 gpa water on March 3, 1970. 2,4-D (1 lb/A) in DMSO (40 gpa) was applied at the 4, 6, 8, 10 and 12 inch stages of growth on March 4, March 10, March 18 and March 27 respectively. Visual observations of top kill were made at biweekly intervals. On May 28, the bulbs were removed from the pots for examination.

The critical information from this study was the verification that early times of treatment of wild garlic with 2,4-D in DMSO gives the greatest reduction in bulb development (Fig. 14) even though rates of top kill were greatest at the later treatment dates (Table 9). Garlic plants in the greenhouse follow a sigmoid growth curve (Fig. 9 and 10) with a maximum height of about 12 inches. After about 60 days, the control plants die and the greater rate of top kill at later treatment stages appears related to the natural senescence and death phenomenon expressed by these greenhouse-grown plants.

As in the previous series of experiments, all 2,4-D treatments significantly reduced bulb development irrespective of CIPC pretreatment (Tables 10 and 11). Enhancement of 2,4-D action by CIPC in terms of bulb development was not apparent (Tables 10 and 11) although a greater rate of top kill was noted at the 6 and 8 inch stages of 2,4-D-DMSO treatment (Table 9). All 2,4-D treated plants produced predominantly soft, white bulbs in contrast to the hard, brown bulbs characteristic of untreated plants and plants receiving CIPC alone (Fig. 13, Table 11). These bulbs showed a tendency to germinate prematurely and rot easily.

Table 9. Days to 100% kill of top growth of greenhouse-grown Wild Garlic plants treated with 2,4-D + DMSO at varying times following pretreatment with 1 lb/A CIPC at the 4-inch stage of development.

1 lb 2,4-D + 40 gpa DMSO/A applied at:	CIPC in water applied at 4-inch stage 0	1 lb/A
4-inch stage	34	-
6-inch stage	34	28
8-inch stage	32	28
10-inch stage	24	22
12-inch stage	19	19

Table 10. Effect of CIPC (1 lb/A) pretreatment in water (40 gpa) and subsequent 2,4-D (1 lb/A) treatment in DMSO (40 gpa) on development of Wild Garlic bulbs in the greenhouse. Data collected 3 months after beginning of the treatments. Plants were collected from the field and transferred to the greenhouse on February 25, 1970.

				Bulbs/pot		
Pretreatment	Height	Treatment	Height	Number	Wt (g)	Wt/bulb (g)
None	-	None	-	59	4.04	0.07
		2,4-D + DMSO	4-inch	1	0.02	0.02
			6-inch	3	0.23	0.07
			8-inch	3	0.50	0.16
			10-inch	27	1.69	0.06
			12-inch	26	1.70	0.07
CIPC, 1 lb/A	4-inch	None	-	47	3.50	0.08
		2,4-D + DMSO	6-inch	3	0.31	0.10
			8-inch	1	0.05	0.05
			10-inch	43	3.69	0.08
			12-inch	27	1.89	0.07

Table 11. Effect of CIPC (1 lb/A) pretreatment in 40 gpa water and subsequent 2,4-D (1 lb/A) treatment in 40 gpa DMSO on development of Wild Garlic bulbs in the greenhouse. Data collected 3 months after beginning of the treatments. Plants were collected from the field and transferred to the greenhouse on February 25, 1970.

				Primary Bulbs			Secondary bulbs			
Pretreatment	Height	Treatment	Height	No/pot	Wt (g)	Wt/bulb (g)	No/pot	Wt (g)	Wt/bulb (g)	Soft
None	-	None	-	24	5.4	0.23	35	2.7	0.08	0/35
		2,4-D + DMSO	4-inch	0	0	0	1	0.02	0.02	1/1
			6-inch	1	0.18	0.18	2	0.10	0.05	1/2
			8-inch	0	0	0	3	0.13	0.04	2/3
			10-inch	1	0.13	0.13	26	1.56	0.06	26/26
			12-inch	5*	0.65	0.13	21	1.05	0.05	19/21
CIPC, 1 lb/A	4-inch	None	-	16	5.0	0.31	31	2.0	0.06	0/31
		2,4-D + DMSO	6-inch	0	0	0	3	0.31	0.10	0/3
			8-inch	0	0	0	1	0.05	0.05	0/1
			10-inch	17*	2.06	0.12	26	1.63	0.06	26/26
			12-inch	2*	0.63	0.32	25	1.25	0.05	23/25

*Primary bulbs white and soft

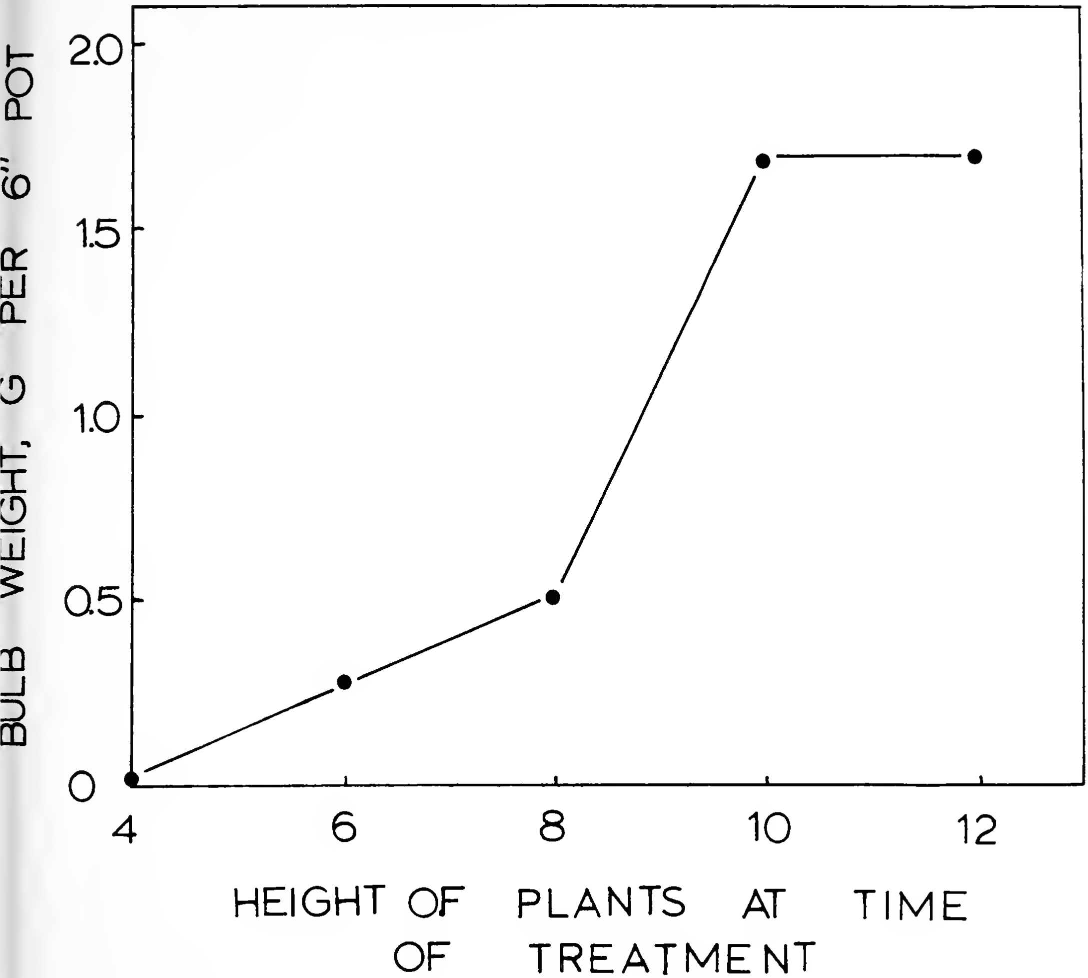


Figure 14. Effect of 1 lb/A 2,4-D in 40 gpa DMSO on bulb development of Wild Garlic in the greenhouse as a function of plant height at the time of treatment. Data collected 3 months after beginning of treatment. Plants were removed from the field February 25, 1970.

Wild Garlic: Stage of Mowing and CIPC pretreatment. - Garlic plants were collected from the field near Lafayette, Indiana on 5 March, 1970 when the plants were approximately 4.5 inches high. CIPC treatments were applied on March 12 at the 5 inch stage of growth just as the plants were recovering and beginning to grow at a constant rate. Pots were clipped at the 6, 8, 10 and 12 inch stage of development on March 12, March 20, March 27 and April 7 respectively to simulate mowing treatments and to determine the effect of mowing on bulb development in the greenhouse.

Results summarized in Table 12 show no effect of mowing or CIPC on reduction of bulb numbers at any stage of treatment. If anything, mowing at the 8 and 10-inch growth stages resulted in an increase in the number of bulbs per pot. Bulb development as affected by CIPC treatment is illustrated for unmowed controls in Fig. 15.

Table 12. Effect of simulated mowing treatments in combination with varying rates of CIPC pretreatment (in 40 gpa water) on development of Wild Garlic bulbs in the greenhouse.

Growth stage at time of mowing	CIPC lb/A	Number of primary bulbs/pot (Number of secondary bulbs per pot is given in parenthesis)				
		0	½	1	2	Ave. (All rates)
6 inch		6 (20)	-	-	-	-
8 inch		19 (56)	18 (75)	35 (81)	6 (45)	19 (64)
10 inch		13 (51)	3 (23)	8 (56)	28 (67)	17 (49)
12 inch		7 (17)	16 (41)	12 (45)	11 (29)	11 (33)
Unmowed		17 (37)	19 (49)	15 (12)	-	17 (33)
Ave. (all stages)		14 (40)	14 (47)	17 (48)	15 (47)	16 (45)

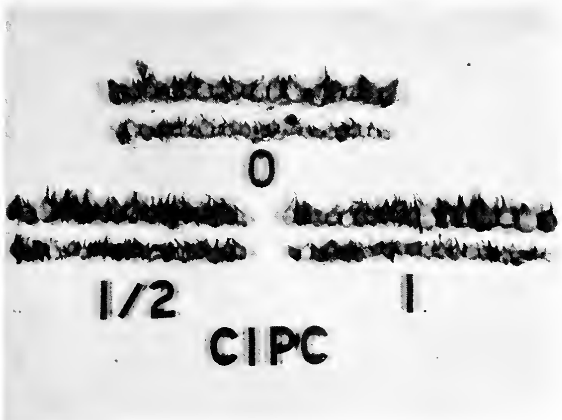


Figure 15. Effect of CIPC at 0, $\frac{1}{2}$, and 1 lb/A applied at the 5-inch stage of growth on formation of Wild Garlic bulbs under greenhouse conditions. Evaluations were made 3 months after beginning of treatments.

Fescue: Effect of CIPC pretreatment on response to 2,4-D in DMSO. Established fescue plants growing in pots were treated with CIPC, 1 lb/A, in 40 gpa water, on March 18, 1970. 2,4-D, 1 lb/A in 40 gpa DMSO, was applied 27 March, 1970. On May 5, the plants were harvested and weighed.

Preliminary observations suggested that CIPC pretreatment might modify 2,4-D action in monocotyledenous plants other than wild garlic. This experiment was designed to test this possibility. Although the fescue plants were not killed by the treatment, growth may have been reduced (Table 13). In general the plants receiving CIPC followed by 2,4-D showed 2,4-D injury symptoms. Both CIPC or 2,4-D alone were without effect.

Table 13

Effect of CIPC pretreatment and treatment with 2,4-D in DMSO alone and in combination on the growth of established fescue in the greenhouse.

Pretreatment	Treatment	Fresh wt. (g)/plant	Visual evaluation of 2,4-D injury
None	None	0.9	-
None	2,4-D in DMSO	1.0	-
CIPC in water	None	0.9	-
CIPC in water	2,4-D in DMSO	0.8	+

Yellow Nutsedge: Effect of CIPC pretreatment on response to 2,4-D in DMSO in the greenhouse.--Established yellow Nutsedge (*Cyperus esculentus*) plants growing in metal pans in the greenhouse were treated on March 18, 1970 with CIPC 1 lb/A in 40 gpa water. 2,4-D (1 lb/A in 40 gpa DMSO) was applied March 27, 1970. On June 30 the plants were harvested and weighed.

Neither 2,4-D nor CIPC alone retarded the growth of Nutsedge (CIPC alone appeared to stimulate growth). The combination treatment of CIPC followed by 2,4-D, however, eventually resulted in death of 75% of the treated plants. Although the killing action was slow in the greenhouse, the treatment showed sufficient promise to be included in the 1970 field tests.

Table 14

Effect of CIPC treatment and treatment with 2,4-D in DMSO alone and in combination on the growth of established Yellow Nutsedge plants in the greenhouse. Evaluated 72 days following treatment.

Pretreatment	Treatment	Fresh wt., g/plant	Ave. ht., inches	% plants dead[1]
None	None	0.187	10	0
None	2,4-D in DMSO	0.197	10	0
CIPC in water	None	0.312	10	16
CIPC in water	2,4-D in DMSO	0.194	9	75

[1]Underground tubers were solid and appeared viable with all treatments.

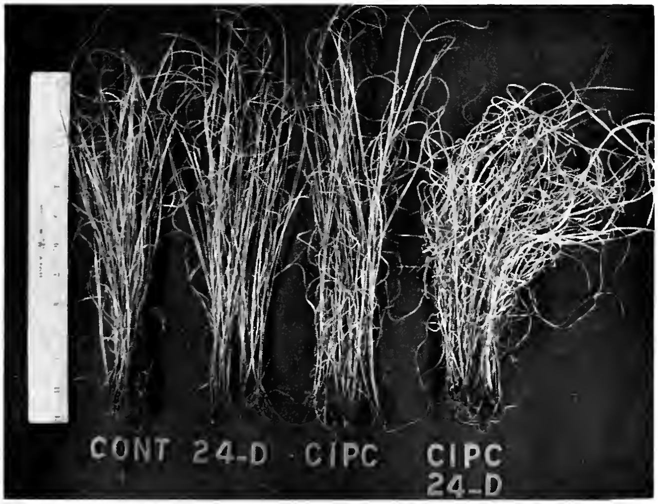


Figure 16. Effect of CIPC pretreatment on control of established Yellow Nutsedge plants in the greenhouse by 2,4-D in DMSO.

1970 Field Trials

Wild Garlic.--A third series of field trials was initiated in Tippecanoe County, Indiana in March 1970 in a roadside situation. A total of 10 treatments were included to compare the effect of various pretreatments on the response of wild garlic plants to 2,4-D applied in water or DMSO as the solvent. Plots were 12' x 20' in an overlapping, nonrandomized block design.

CIPC was applied to one-half the area on March 21, 1970 at a rate of 1 lb/A in 40 gpa water when the plants were approximately 5 inches tall and just prior to the grand period of constant growth rate (Fig. 17). 2,4-D (1 lb/A) in DMSO or water as the solvent (40 gpa) was applied April 16, 1970 when the plants were 7.5 inches tall and just beginning to grow rapidly (Fig. 17).

Since cuticle and surface wax deposits appears important to effectiveness of 2,4-D in DMSO treatments, one-half of the control and CIPC-treated areas were beaten with a lawn rake to mechanically rupture the leaf surface (cuticle disrupted mechanically) just prior to application of the 2,4-D in DMSO. Plants were beaten until flat on the ground but care was taken to cut off none of the foliage.

In 1970, growth of Wild Garlic in the field proceeded slowly in February and March at a rate of about 1/30 inch/day (Fig. 17). About April 1, growth rate increased markedly to about 0.5 inch/day during mid April and early May (a rate comparable to that observed in the greenhouse). A maximum average height of about 2 ft. was reached about June 1 at which time the plants produced flowers. Flowering was followed by senesence and death, Growth of wild garlic plants in the greenhouse (Figs. 9 and 10) paralleled that in the field (Fig. 17) except that greenhouse grown plants reached a maximum height of about 1 ft and did not flower.

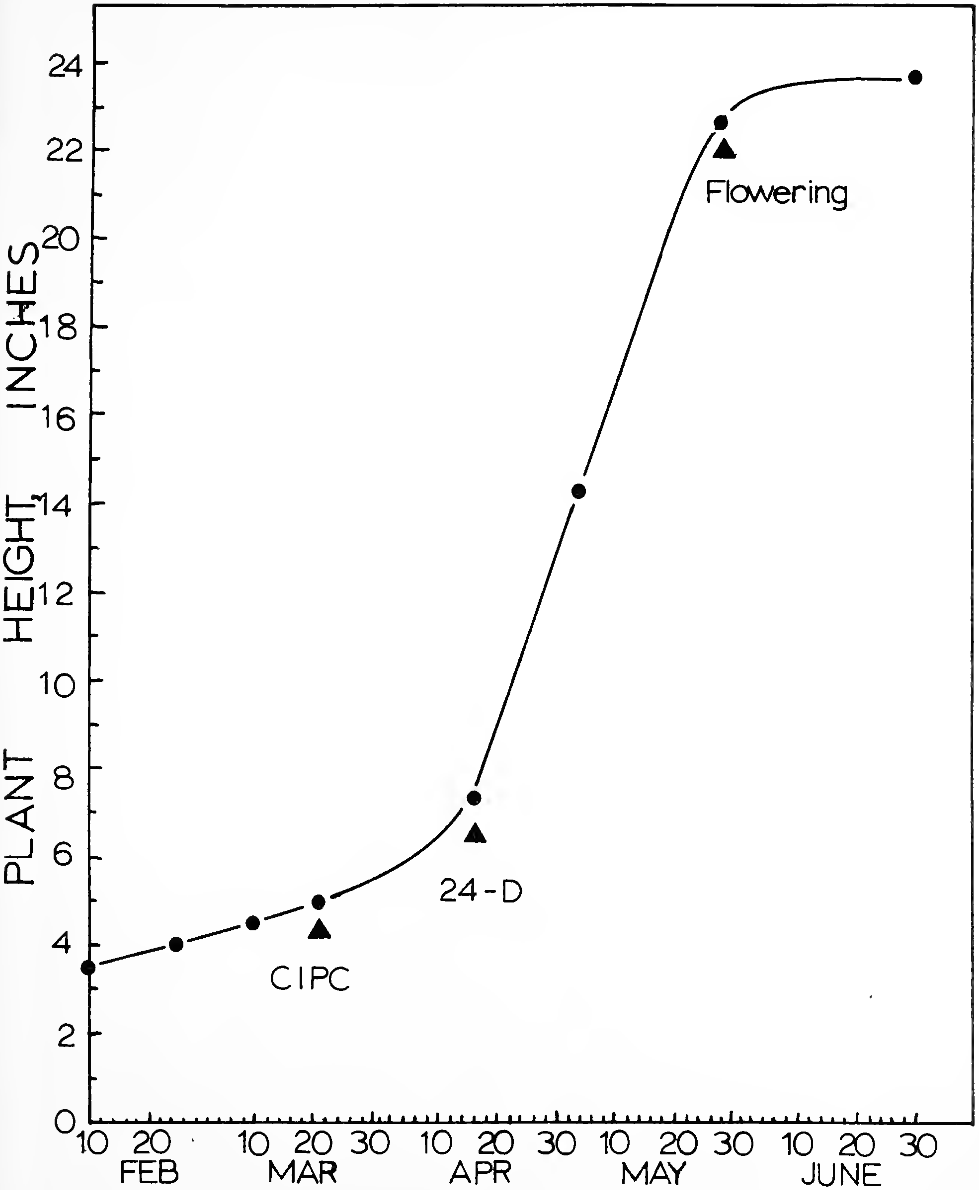


Figure 17. Growth of Wild Garlic plants in the field in 1970. The test area was a roadside situation along U.S. 52 NW of Lafayette, Indiana. Arrows indicate stages during which CIPC and 2,4-D were applied to treated plots and the time of flowering.

Visual estimates of top kill on May 5, 1970, approximately 3 weeks after treatment (Table 15) showed considerable deformation and loss of chlorophyll in all plants receiving 2,4-D. Those treatments in which the cuticle was ruptured mechanically were most severely damaged. In these plots, tissue proliferation was noted at the base of the plant and extending into the bulb. We could see no effect of the CIPC pretreatment at this time and results with 2,4-D applied in either water or DMSO appeared comparable.

More extensive observations on effects of the various treatments on growth and development of Wild Garlic were obtained approximately 6 weeks following treatment at about the time the plants normally flower (Fig. 18, 19, 20). All treatments reduced plant height as well as shoot and bulb weight per plant (Table 16). All plants receiving 2,4-D were deformed and chlorotic (Fig. 19, 20). The most effective treatments were those in which the cuticle was ruptured mechanically prior to application of 2,4-D (Table 16). In terms of control of top growth alone, the CIPC treatment had little or no effect (Fig. 18, Table 16) and applications of 2,4-D either in water or DMSO were equivalent (Table 16).

In contrast, in those treatments where the plants were treated in the absence of mechanical rupture of the cuticularized surface layers, the CIPC pretreatment had an appreciable effect (Table 16). Plants treated with CIPC 3½ weeks prior to application of 2,4-D gave nearly 58% less growth of bulbs and shoots as the plants not receiving CIPC. Again, it seemed to make little or no difference if the 2,4-D was applied in DMSO or water.

TABLE 15

Visual estimates to top kill of Wild Garlic in the field in 1970 approximately 3 weeks following final treatment with 2,4-D.

Pretreatment	Treatment	Solvent	Top kill index*	Deformation index**
None	None	-	0	2
	1 lb/A 2,4-D	Water	4	7
		DMSO	4	6
CIPC, 1 lb/A	None	-	0	2
	1 lb/A 2,4-D	Water	4	7
		DMSO	4	6
Cuticle ruptured mechanically prior to treatment with 2,4-D ± DMSO***				
None	1 lb/A 2,4-D	Water	6	7
		DMSO	6	8
CIPC, 1 lb/A	1 lb/A 2,4-D	Water	7	7
		DMSO	7	8

* 0 = no top kill; 10 = complete kill of top growth

** 0 = no deformation; 10 = all plants curled and twisted

*** To mechanically rupture surface waxes and cuticle, leaves were beaten with a lawn rake.

Fig. 19. Wild Garlic plants in roadside test plot pretreated with 1 lb/A CIPC on March 21, 1970 followed by mechanical rupture of the cuticle and treatment with 1 lb/A 2,4-D in water on April 16, 1970. Photographed May 5, 1970.

Fig. 18. Wild Garlic plants in roadside test plot treated with 1 lb/A CIPC on March 21, 1970. Photographed May 5, 1970.

Fig. 20. Wild Garlic plants in roadside test plots treated as in Fig. 19 showing the abnormal and twisted growth resulting from the combination treatment.

TABLE 16

Final evaluation of 1970 field treatments for control of Wild Garlic. Plants were pretreated March 22, 1970 at the 5-inch stage of growth with or without 1 lb/A CIPC followed by treatment on April 16 at the 7½-inch stage of growth with or without 1 lb/A 2,4-D amine in DMSO or water (40 gpa). Plants in one-half of each treated plot were beaten with a lawn rake to mechanically rupture the surface cuticle and waxes. Evaluations were on May 28, 1970 approximately 6 weeks following treatment.

Pretreatment	Treatment	Solvent	Plant height (inches)	Fresh weight (g) plant Shoots	Fresh weight (g) plant Bulbs
None	None	-	22	1.16	2.01
	1 lb/A 2,4-D	Water	14	0.87	0.91
		DMSO	17	0.81	1.04
CIPC, 1 lb/A	None	-	22	0.86	1.13
	1 lb/A 2,4-D	Water	12	0.46	0.45
		DMSO	14	0.33	0.80
Cuticle ruptured mechanically prior to treatment with 2,4-D ± DMSO					
None	1 lb/A 2,4-D	Water	10	0.78	0.47
		DMSO	16	0.38	0.64
CIPC, 1 lb/A	1 lb/A 2,4-D	Water	9	0.18	0.39
		DMSO	10	0.58	0.41

Final evaluation of treatment effectiveness depended upon the examination of the condition of the plants, especially in terms of the viability and reproductive capacity of the treated plants. These results are summarized in Tables 16 & 17. All treatments except CIPC alone reduced flowering and the number of primary bulbs (Table 17). Only with the combination treatment CIPC followed by mechanical disruption of cuticle + 2,4-D + DMSO was flowering completely supressed. Viable primary bulbs were absent from all treatments consisting of CIPC followed by mechanical disruption of cuticle + 2,4-D irrespective of whether the 2,4-D was applied in DMSO or not. Secondary bulblets were reduced most effectively by mechanical disruption of cuticle followed by 2,4-D. 2,4-D applied in either water or DMSO resulted in extensive bulb damage. However, as evidenced by the degree of decomposition, 2,4-D applied in water appeared to result in more rapid bulb kill than 2,4-D applied in DMSO.

In these studies, effective kill of primary bulbs by 2,4-D was dependent upon pretreatment of the plants with CIPC. In general, CIPC alone had no detremental effect on bulbs. 2,4-D alone resulted in the killing of a few bulbs. The combination CIPC followed by 2,4-D caused extensively deformed bulbs which at the time of examination were decomposing rapidly and in many the roots were already dead. These results are shown in Fig. 21-36 and are indicative of true synergism. In spite of the synergistic interaction of CIPC and 2,4-D, mechanical disruption of the cuticle was necessary in order to achieve effective control of Wild Garlic with the combination (Table 16).

TABLE 17

Final evaluation of 1970 field treatments for control of Wild Garlic. Plants were pretreated March 22, 1970 at the 5-inch stage of growth with or without 1 lb/A CIPC followed by treatment on April 16 at the $7\frac{1}{2}$-inch stage of growth with or without 1 lb/A 2,4-D amine in DMSO or water (40 gpa). Plants in one-half of each treated plot were beaten with a lawn rake to mechanically rupture the surface cuticle and waxes. Evaluations were on May 28, 1970 approximately 6 weeks following treatment.

Pretreatment	Treatment	Solvent	% Mature plants flowering	% plants with solid primary bulbs	Firm Secondary underground bulblets/plants
None	None	-	100	100	1.6
	1 lb/A 2,4-D	Water	50	86	1.4
		DMSO	80	87	1.3
CIPC, 1 lb/A	None	-	100	96	1.2
	1 lb/A 2,4-D	Water	30	82	1.1
		DMSO	62	80	1.0
Cuticle ruptured mechanically prior to treatment with 2,4-D $\pm$ DMSO					
None	1 lb/A 2,4-D	Water	7	50	0.8
		DMSO	7	42	0.5
CIPC, 1 lb/A	1 lb/A 2,4-D	Water	8	0*	0.2
		DMSO	0	0*	0.9

* Both treatments resulted in extensive bulb damage. However, as evidenced by the degree of decomposition, 2,4-D applied in water appeared to result in more rapid bulb kill than 2,4-D applied in DMSO.

The basis for the CIPC followed by 2,4-D interaction remains elusive. Data obtained under conditions of garlic treatment in the field do not confirm the greenhouse observations that CIPC pretreatment caused a significant reduction in the amount of waxy surface deposits on the leaves (Table 18). Additionally, we could determine no evidence of increased bulb or top growth due to CIPC in the field (Table 16). These studies do show, however, that in contrast to greenhouse-grown plants, field-grown garlic plants continue to produce wax during periods of rapid growth (Table 18) although not in amounts commensurate with increase in plant height or weight. These results are also consistent with the hypothesis that the ineffectiveness of DMSO in the field is due to the greater abundance of surface wax on field grown plants. However, that mechanical disruption of cuticle did not enhance DMSO effectiveness suggests that alternative explanations should be considered as well.

TOTAL PLANTS

Fig. 21. Untreated

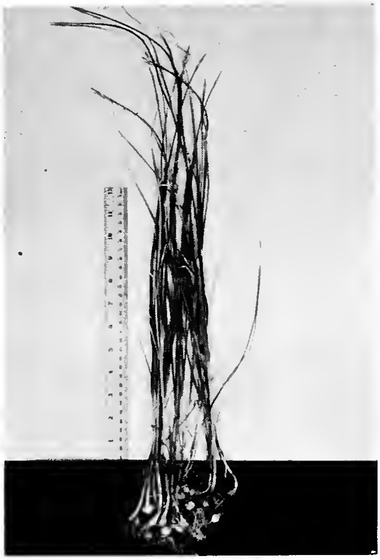


Fig. 22. CIPC pretreatment

Figures 21-36. Final evaluation of 1970 field treatments for control of Wild Garlic. Plants were pretreated March 22, at the 5-inch stage of growth with or without 1 lb/A CIPC followed by treatment on April 16 at the $7\frac{1}{2}$-inch stage of growth with or without 1 lb/A 2,4-D amine in DMSO or water (40 gpa). Plants in one-half of each treatment were beaten with a lawn rake to mechanically rupture the surface cuticle and waxes. Plants were photographed May 28 applroximately 6 weeks following treatment.

TOTAL PLANTS

Fig. 23. No pretreatment
2,4-D in water treatment

Fig. 24. No pretreatment
Cuticle ruptured mechanically
2,4-D in water treatment

Fig. 25. CIPC pretreatment
2,4-D in water treatment

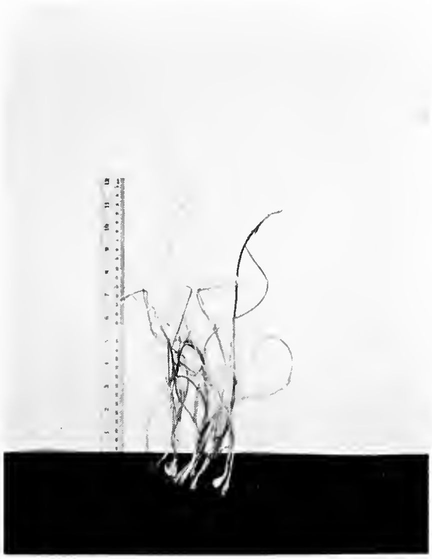


Fig. 26. CIPC pretreatment
Cuticle ruptured mechanically
2,4-D in water treatment

TOTAL PLANTS

Fig. 27. No pretreatment
2,4-D in DMSO treatment

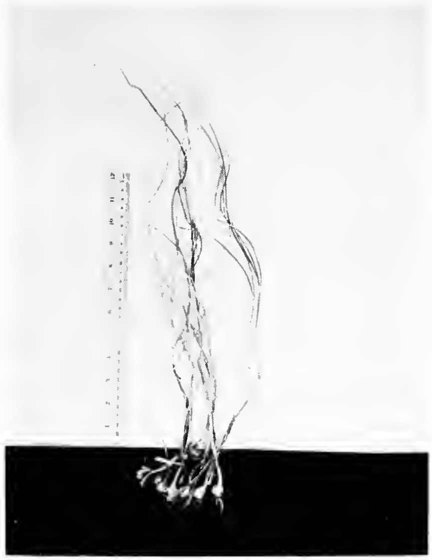


Fig. 28. No pretreatment
Cuticle ruptured mechanically
2,4-D in DMSO treatment

Fig. 29. CIPC pretreatment
2,4-D in DMSO treatment

Fig. 30. CIPC pretreatment
Cuticle ruptured mechanically
2,4-D in DMSO treatment

BULB GROWTH

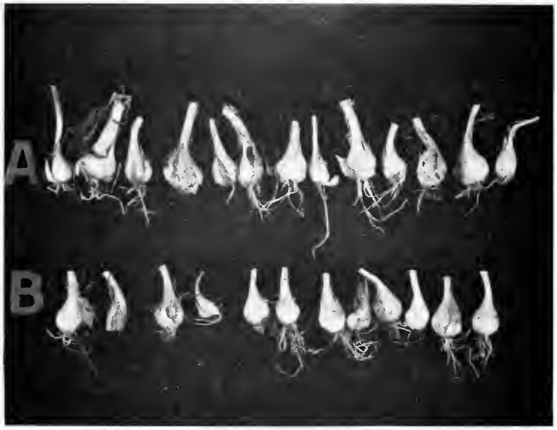


Fig. 31. A. No pretreatment B. CIPC pretreatment
2,4-D in water treatment

Fig. 32. C. No pretreatment D. CIPC pretreatment
Cuticle ruptured mechanically
2,4-D in water treatment

BULB GROWTH

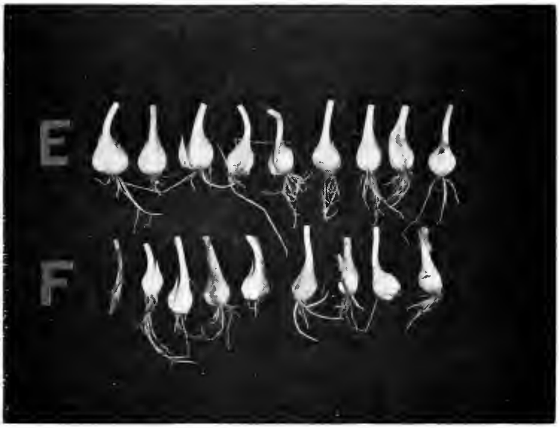


Fig. 33. E. No pretreatment F. CIPC pretreatment
2,4-D in DMSO treatment

Fig. 34. G. No pretreatment H. CIPC pretreatment
Cuticle ruptured mechanically
2,4-D in DMSO treatment

BULB GROWTH

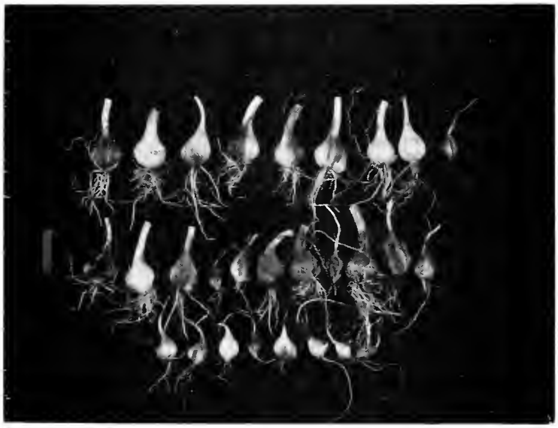


Fig. 35. I. CIPC pretreatment alone

Fig. 36. J. Untreated plants

TABLE 18

Effect of 1 lb/A CIPC applied March 21, 1970 at the 5-inch stage of growth on surface wax development on leaves of Wild Garlic in the field.

Date	Treatment	Mg/plant	Mg/g dry weight
April 16	None	0.48	0.50
	CIPC	0.45	0.45
May 5	None	0.33	0.35
	CIPC	0.90	0.28

Yellow Nutsedge. Established Yellow Nutsedge (Cyperus esculentus) growing under roadside conditions in Bluegrass turf was mowed to a height of about 4 inches on June 1. The following day the plants were treated with 1 lb/A of CIPC in 40 gpa water. The plants were again mowed and treated with 1 lb/A 2,4-D in 40 gpa water on June 18. Plants were photographed June 29.

The field studies with Yellow Nutsedge confirmed the greenhouse studies in that CIPC followed by 2,4-D proved effective as a control measure for this normally 2,4-D-resistant monocot (Fig. 37). Evaluations 2 months after treatment revealed no regrowth from the treated Nutsedge plants whereas control plants were still producing new growth. The Bluegrass was not killed by any of the treatments.

These studies with Yellow Nutsedge, although preliminary, suggest the possibility that CIPC may alter the selectivity pattern of plant species normally resistant to 2,4-D in such a way that they become susceptible to 2,4-D. The results with Wild Garlic and established Fescue support this interpretation. So far, desirable turf grasses seem to withstand the treatment sufficiently well to warrant continued testing. Further studies will be necessary to evaluate the effectiveness of this treatment against other undesirable monocot species and to quantitate its effects on desirable species.

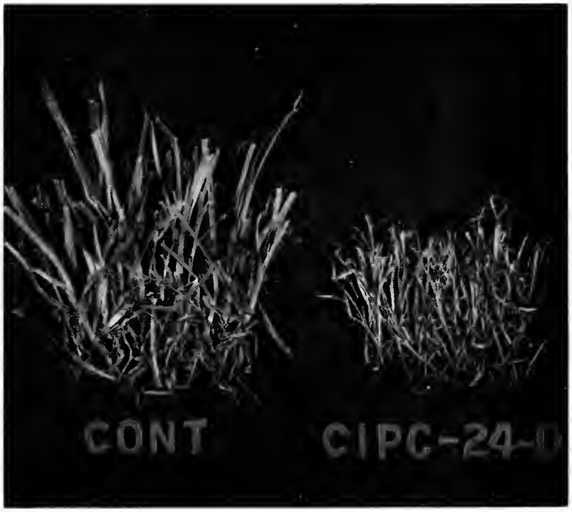


Figure 37. Effect of CIPC (1 lb/A) in water followed by 2,4-D (1 lb/A in water) 16 days later on control of Yellow Nutsedge under roadside conditions.

SUMMARY

Combinations of Tordon herbicide plus 2,4-D, 2,4,5-T or Dicamba applied in water or DMSO as solvent were studied under laboratory, greenhouse and field conditions for control of Wild Garlic (Allium vineale).

2,4-D alone was found to be superior or equivalent to any of the herbicides or combinations of herbicides tested for control of Wild Garlic and considerably cheaper.

In greenhouse studies, 2,4-D action was enhanced by application of the herbicide in DMSO. This effect was not demonstrated in the field even under conditions where the waxy surface layers of the plants were disrupted mechanically prior to application of the herbicide in DMSO.

Pretreatment of the plants with 1 lb/A CIPC several weeks to application of the 2,4-D resulted in complete control of primary bulblets and top growth. Secondary bulblets were reduced in the field under these conditions and it remains to be determined to what extent respraying will be necessary to achieve eradication.

2,4-D + CIPC combination treatments were most effective applied early in the growing season at the 4-5 inch growth stages. Treatment effectiveness declined with increasing plant height. Treatments were ineffective when the plants were 10-12 inches tall at the time of treatment.

III. COMMON MILKWEED

INTRODUCTION

Similarities of growth responses between plants (13) or plant parts (9) treated with 2,4-D or Tordon herbicide have suggested a common mode of action for the two growth regulators. However, a synergistic or enhanced response for Tordon and 2,4-D or Tordon and 2,4,5-T herbicide mixtures has also been indicated in reports of field applications for control of Macartney rose (Rosa bracteata) (5), blackberry (10), weeds in small grains (12), general brush control (10, 24), control of deep rooted perennials (2), roadside vegetation (4, 20) and in laboratory and greenhouse assays (8, 20). The following report is an analysis of 2,4-D-Tordon herbicide interactions using intact plants and seedlings under controlled conditions, with emphasis on the effectiveness of Tordon herbicide alone and combinations with 2,4-D or 2,4,5-T for control of common milkweed (Asclepias syriaca).

Common Milkweed is an especially troublesome roadside weed. It is a perennial growing from an extensive system of underground rhizomes (Fig. 38) and is not controlled by mowing or by any of the more common roadside spraying programs. It grows to a height of 4-5 ft (Fig. 39), is unsightly and frequently obstructs visibility especially along unimproved roads.

PROCEDURE

Laboratory Studies

Common Milkweed (Asclepias syriaca) and Cucumber (Cucumus sativus L., var. Chicago Pickling) seeds were placed, 15 per dish, on circles of

Figure 38. Segments of two plants of Common Milkweed, <u>Asclepias syriaca</u>, showing typical rhizome development in the field.

Figure 39. Harvesting rhizomes in the milkweed test area along U.S. 52 NW of Lafayette, Indiana in early September 1968. At this stage, plants are about 5 ft tall.

Whatman No. 2 filter paper which were contained in 1 x 10 cm petri dishes with 6 ml of the solutions to be tested. After 72 hrs (dark, 24 $\pm$ 0.5^{o}C), the length of the primary root was recorded. Results are the average of 3 experiments with triplicate dishes in each experiment (135 seedlings per point).

Greenhouse Studies

Growth of milkweed. - Common milkweed (Asclepias syriaca) plants were grown in the greenhouse either from seed or from rhizomes collected from local natural infestations. Seeds were placed in soil at a depth of 1 cm and the seedlings were thinned to two plants per 6 inch pot. Prior to germination, seeds were stratified for 12 weeks at 0 to 4^{o}C. Under these conditions germination was about 90%. Rhizome pieces were selected for uniformity and those with buds were placed 3 to 4 cm below the soil surface. Three rhizome segments were used per 6 inch pot. Plants grown from seed were treated 3 months after seeding. Plants grown from rhizomes were treated after 3.5 months. Plants were sprayed as described for bean plants. Results are the average of 25 plants from 5 replicates in each of two experiments.

Growth of bean plants - Bean (Phaseolus vulgaris L., var. Red Kidney) plants were grown in soil overlayed with a soil-sand (1:1) mixture (4 plants per 6 inch pot) in the greenhouse (20 to 23^{o}C). When the plants were 20 days old, treatments were applied using an atomizer in 3 ml of solution per 4 plants (ca. 50 gpa). Fresh weights of shoots were determined to the nearest 0.1 g at intervals of about 2 days for 18 days after treatment. Results are the average of 48 to 60 plants.

Field Studies

Studies were conducted on roadside situations in the vicinity of Lafayette, Indiana in the summer and fall of 1967 and 1968. Plots 7 m x 7 m were treated using a single nozzle (8002) hand sprayer, with plants wetted to point of runoff (ca. 50 gpa and 40 psi). All treated plots were separated by a buffer strip to reduce cross interactions among treatments. Best results were obtained when plants were treated in the late bloom stage of development (mid-August) just as the follicles were beginning to form. Visual observations of foliar toxicity were made at intervals of about 2 weeks. To evaluate the effectiveness of treatments in controlling below ground parts, rhizomes were sampled at intervals of approximately 1, 2, 3, 4, 6 and 8 weeks following treatment. The entire lateral rhizome system was sampled and vertical rhizomes were sampled to a depth of about 40 cm. After sampling, representative rhizome pieces were placed in the greenhouse, 3 per 6 inch pot, and those producing shoots (even though the shoots did not produce plants) were scored as viable. After 10 weeks, the rhizomes were removed from the pots and examined for signs of deterioration. Germinability of seed was determined in the laboratory ca. 1.5 months after spraying. The seeds were stratified at 0 to 4^{o}C and germination percentages determined 2, 4, 6 and 8 weeks after harvest.

Preparation of Herbicide Solutions

For studies with seedlings in the laboratory, potassium 2,4-D or Tordon (Dow Analytical Grade, 99%) was dissolved in 2 mm potassium maleate buffer, pH 4.5, without aid of cosolvent. For field and green-

house studies with bean and milkweed, Tordon 22K weed killer or commercial formulations of 2,4-D and 2,4,5-T (as the butyl ester) were mixed with deionized water. All dosages were calculated on an acid equivalent (ae) basis.

RESULTS AND DISCUSSION

Choice of Herbicide

Preliminary laboratory testing of herbicides for control of Common Milkweed involved procedures which checked growth of freshly harvested Milkweed rhizomes in agar mixed with varying concentrations of the herbicide as well as effects on growth of germinating Milkweed seedlings. Tordon herbicide was found to be highly active in both these assays (Tables 19 and 20) and this compound was tested further in the greenhouse as a possible herbicide for control of Common Milkweed.

Greenhouse tests showed Tordon to be the only material commercially available at that time capable of killing both tops and rhizomes of Milkweed plants at reasonable rates of application. As an example, results with Tordon and the two more common roadside herbicides 2,4-D and 2,4,5-T are compared in Table 21.

Symptom Expression

One major difference between 2,4-D and Tordon herbicide was in the rate of symptom expression. This feature of its pattern of action may contribute to the greater effectiveness of Tordon for control of Common Milkweed as well as other species of perennial broad-leaved plants (1, 4, 18). In model experiments with bean, control plants more than doubled in fresh weight during a 20 day period following treatment (Fig. 40).

Plants treated with either herbicide grew rapidly at first but between 3 and 4 days, began to decline in fresh weight (Fig. 40). The decline for 2,4-D-treated plants was linear and rapid after about 3 days. Plants treated with Tordon herbicide began to decline in fresh weight between 4 and 8 days but remained turgid between 8 and 14 days with little or no change in fresh weight. Then, beginning about 14 days, the plants again began to lose weight rapidly and were completely dessicated in about 20 days. Although the killing action of Tordon was slow compared to that of 2,4-D, the final fresh weight of the Tordon-treated plants after 20 days was less (Fig. 41). A similar situation was observed visually for milkweed growing and treated both in the field and in the greenhouse comparing Tordon herbicide with both 2,4-D and 2,4,5-T.

Table 19. Inhibition of sprouting of Common Milkweed root segments cultured in agar.

		Shoots per 12 root segments		
Treatment	Conc	Aug. 20	Aug. 28	Sept. 29
Control	--	11	10	7
Tordon	10^{-6} M	10	7	3
	10^{-5} M	4	3	0
	10^{-4} M	9	0	0
	10^{-3} M	3	0	0

Table 20. Root inhibition of germinating Common Milkweed seeds by Tordon and 2,4-D alone and in combination (3 days after treatment).

	Length of radical, mm		
Treatment	10^{-5}	10^{-6}	10^{-7} M
Tordon	2.6	11.1	34.2
2,4-D	7.8	20.9	37.5
Comb 1 + 3	3.0	20.4	33.9
Comb 2 + 2	3.3	12.8	24.2
Comb 3 + 1	2.3	6.4	23.1
Control		52.3	

Table 21. Effect of varying rates of 2,4-D and Tordon, alone and in combination, in 50 gpa water on growth of established plants of Common Milkweed in the greenhouse. Observations were taken 4 weeks following treatment. Average of 2 experiments.

	lb/A total herbicide											
	Shoots				Roots				Total plant			
Herbicide	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0
	Grams Fresh Weight											
Tordon	4.4	3.0	2.0	2.0	3.8	3.1	1.7	0.4	8.2	6.1	3.7	2.4
2,4-D	7.0	8.1	5.0	5.0	5.6	7.8	5.8	4.1	12.6	15.9	10.8	9.1
2,4,5-T	8.2	6.8	8.9	3.3	6.5	6.0	5.9	6.2	14.7	12.8	12.8	9.2
None		14.2				8.7				22.9		

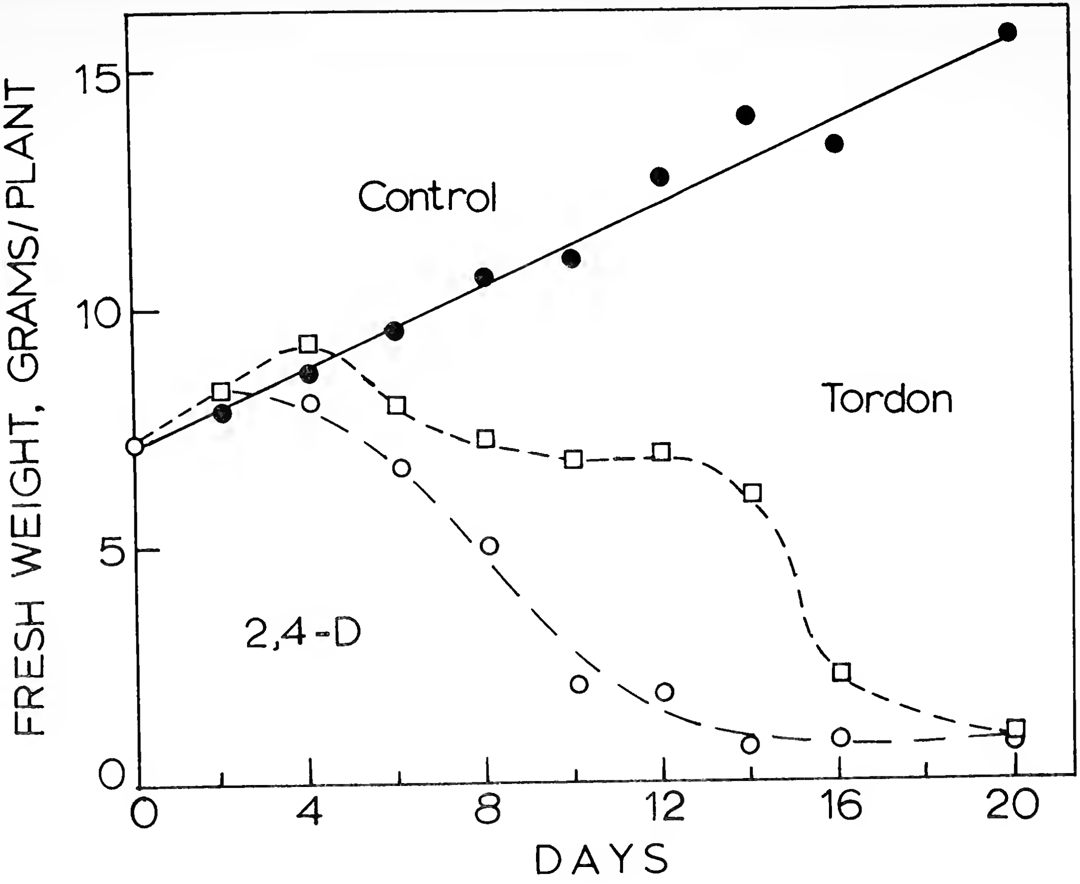


Figure 40. Decrease in fresh weight of bean plants treated in the presence and absence of 0.5 lb per acre of Tordon herbicide or butyl-2,4-D ae as a function of days after treatment. Plants were watered on the days prior to sampling and treatment.

Replacement Studies

Laboratory tests with beans and cucumbers. - Tordon herbicide is somewhat more expensive than either 2,4-D or 2,4,5-T and an attempt was made to see if a portion of the Tordon required to kill Milkweed plants could be replaced by less costly herbicides. Beans and cucumbers were chosen as the test plants for preliminary studies.

With bean, which is a 2,4-D-susceptible species, up to 3/4 of the Tordon could be replaced in the mixture without any loss of treatment effectiveness (Compare 1/16 lb/A Tordon + 3/16 lb/A 2,4-D with 1/4 lb/A tordon in Table 22). Data averaged from 3 experiments with 5 replicates each is presented graphically in Figure 41. These results show that at 0.25 and 0.5 lb/A, all combinations were more effective than 2,4-D alone and nearly comparable to Tordon herbicide alone in reducing the final weight of the plants after 18 days. Although the tendency of these results is to indicate an apparent synergism between the 2,4-D and Tordon (in that all combinations are displaced in the direction of Tordon), this apparent synergism is valid for the mixtures containing 75% Tordon and 25% 2,4-D at all dosage levels but true for other mixtures only at the 1/4 and 1/2 lb/A rates.

Table 22. The effect of Tordon or 2,4-D, alone and in combination on the growth of Red Kidney Bean plants (18 days old) 9 days after treatment. Total herbicide was 1/4 lb/A.

Acid equivalent percent by weight in mixture applied		Fresh weight per 5 plants, grams	
2,4-D	Tordon	Shoots	Roots
0	0	28.9	7.0
0	100	8.3	0.7
25	75	7.8	0.6
50	50	7.9	0.5
75	25	8.2	0.4
100	0	19.1	1.2

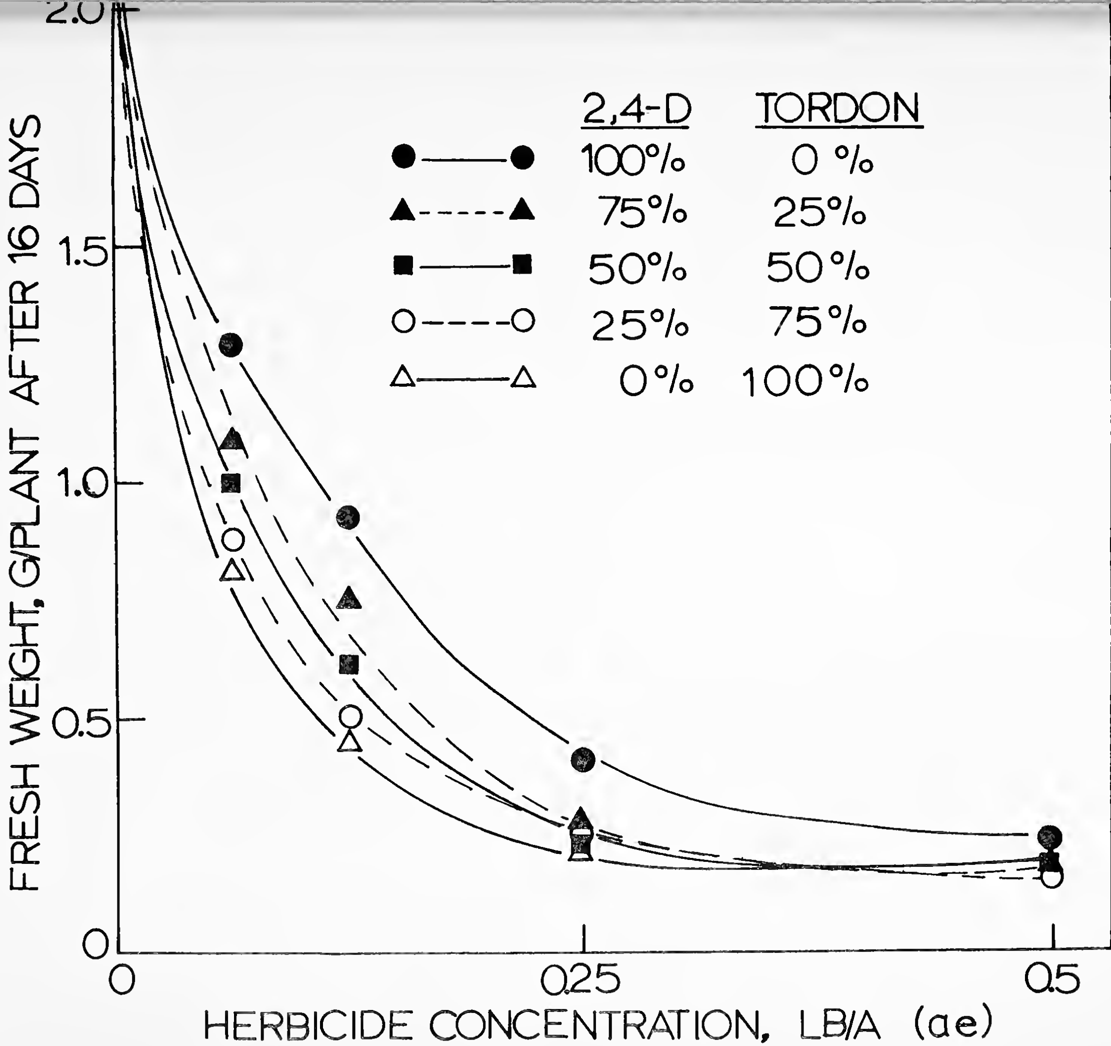


Figure 41. Effect of Tordon herbicide or butyl-2,4-D on the fresh weight of bean plants 18 days after treatment as a function of ae herbicide concentration. Results are based on 3 experiments with 5 replicates each (total of 60 plants).

Some insight into the nature of the interaction has been obtained from laboratory studies. Results with primary roots of cucumber seedlings (Fig. 42 A) show an apparent synergism comparable to that for bean (Fig. 41) except that 2,4-D is the more potent component of the mixture for inhibition of root growth. Closer analysis shows that these results can be explained by assuming that the roots respond only to the 2,4-D of the mixture (Fig. 42 B). In Fig. 42 B, the data are replotted according to the amount of 2,4-D present in the combination irrespective of any Tordon present. Since all data points fit the log linear function established as the 2,4-D concentration curve for inhibition of cucumber root growth (Fig. 42 A), one interpretation is that 2,4-D is strongly competitive with Tordon in inhibiting root growth of cucumber seedlings. Similar results were obtained with studies of root growth of germinating milkweed seedlings.

With excised corn coleoptile sections, Tordon and 2,4-D were found to be competitive in their ability to promote rapid cell elongation at high concentrations but weakly competitive (or additive) at lower concentrations. These results will be reported later in connection with a more complete comparison of the modes of action of these and other growth regulators of the auxin type.

<u>Greenhouse tests with milkweed</u>. - As with bean, herbicide mixtures containing 75% Tordon plus 25% 2,4-D or 2,4,5-T were comparable to Tordon herbicide alone at all dosage levels (except 0.125 lb 2,4,5-T) (Tables 23, 24, 25, 26). Combinations containing 50% or 75% 2,4-D were consistently more effective than 2,4-D alone at the higher treatment rates but the

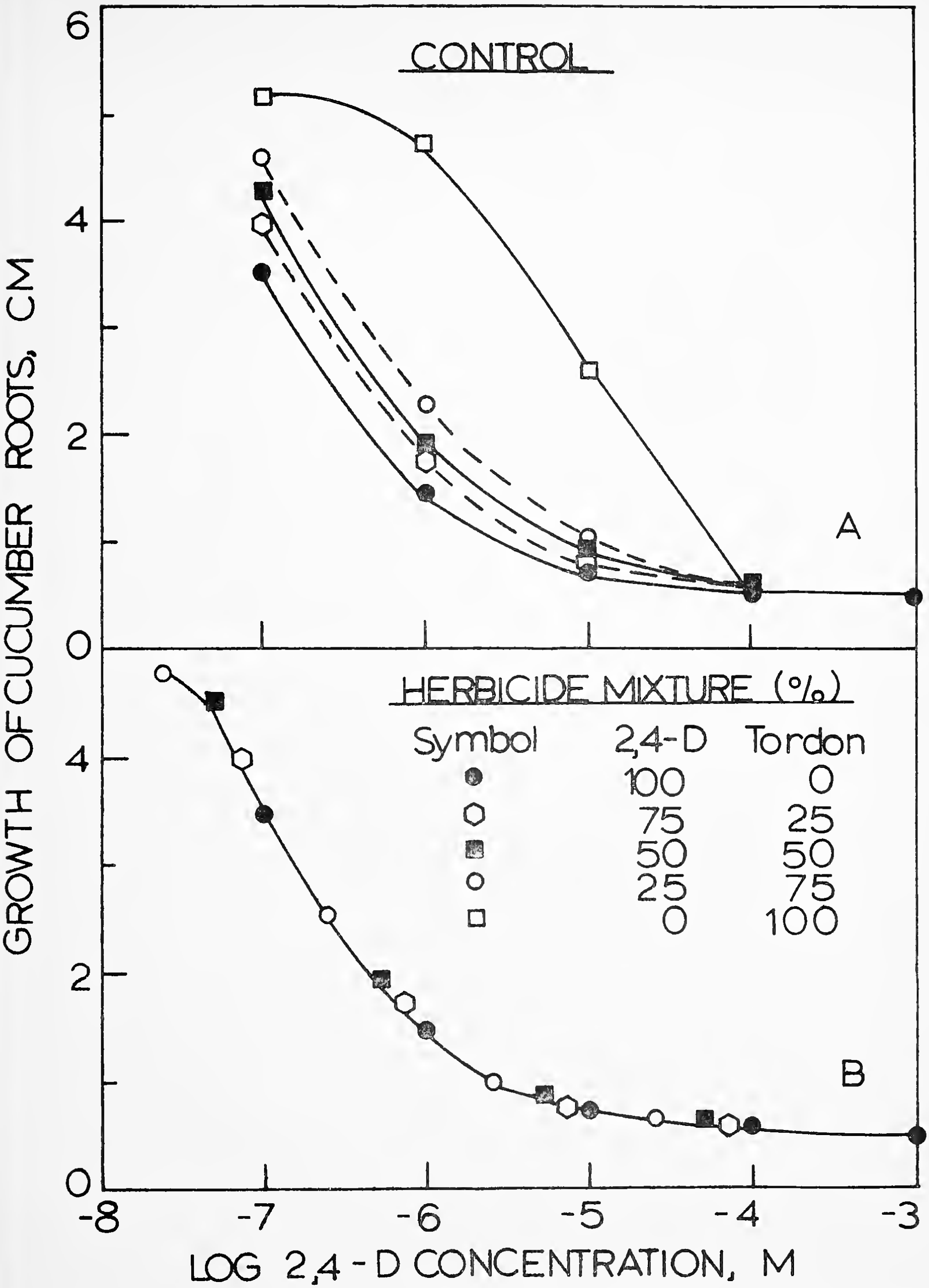


Figure 42. Effect of Tordon herbicide or potassium 2,4-D on the growth of primary roots of germinating cucumber seedlings. A. As a function of total growth regulator concentration comparing 2,4-D and Tordon herbicides alone and in various combinations. B. Data of part A replotted as a function of the amount of 2,4-D present in the mixture.

Table 23. Effect of varying rates of 2,4-D and Tordon, alone and in combination, in 50 gpa water on growth of established plants of Common Milkweed in the Greenhouse. Observations were taken 4 weeks following treatment. Plants grown from rhizomes July 1967.

Percent of mixture		% Top kill, lb/A total herbicide							
		Leaves				Stems			
2,4-D	Tordon	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0
100	0	50	56	62	76	44	46	32	66
75	25	64	68	68	66	64	64	64	64
50	50	84	72	88	100	82	72	86	100
25	75	88	100	100	100	82	100	100	100
0	100	88	96	100	100	82	88	100	100
0	0		0				0		

Table 24. Effect of varying rates of 2,4-D and Tordon, alone and in combination, in 50 gpa water on growth of established plants of Common Milkweed in the greenhouse. Observations were taken 4 weeks following treatment. Plants grown from seed January 1968.

Percent of mixture		% Top kill, lb/A total herbicides							
		Leaves				Stems			
2,4-D	Tordon	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0
100	0	8	40	40	60	4	4	14	22
75	25	44	60	82	76	43	62	38	44
50	50	50	84	52	88	43	66	46	76
25	75	62	90	80	96	48	78	74	84
0	100	85	84	86	100	48	64	74	90
0	0			0				0	

Table 25. Effect of varying rates of 2,4-D and Tordon, alone and in combination, in 50 gpa water on growth of established plants of Common Milkweed in the greenhouse. Observations were taken 4 weeks following treatment. Average of 3 experiments.

Percent of mixture		Grams fresh weight, lb/A total herbicide											
		Shoots											
2,4-D	Tordon	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0
100	0	7.8	8.5	5.6	5.4	5.9	8.8	6.7	4.3	15	17	13	10
75	25	9.2	6.6	3.5	3.1	9.4	3.9	3.5	2.5	13	11	7	6
50	50	7.9	3.6	3.0	4.3	3.1	2.8	4.1	1.0	11	7	7	5
25	75	5.1	2.4	1.7	2.1	4.3	2.7	0.6	0.9	9	3	2	3
0	100	4.2	3.7	2.0	2.2	2.8	4.6	0.5	0.2	7	9	3	2
0	0		18.9				9.9				29		

Table 26. Effect of varying rates of 2,4-D and Tordon, alone and in combination, in 50 gpa water on growth of established plants of Common Milkweed in the greenhouse. Observations were taken 4 weeks following treatment. Average of 3 experiments.

Percent of mixture		Grams dry weight, lb/A total herbicide											
		Shoots				Roots				Total plant			
2,4-D	Tordon	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0	0.25	0.5	1.0	2.0
100	0	4.1	3.6	2.6	2.6	2.1	3.2	2.6	1.3	6.3	6.8	5.2	3.9
75	25	3.9	2.7	2.3	3.0	3.4	1.2	0.6	0.9	7.3	3.9	2.9	3.9
50	50	3.1	1.6	3.1	1.9	1.1	0.8	1.4	0.5	4.2	2.4	3.5	2.4
25	75	2.6	2.2	1.6	2.0	1.3	0.6	0.2	0.2	3.9	2.8	1.8	2.2
0	100	2.0	2.9	1.6	2.5	1.1	1.4	0.2	0.1	3.1	4.3	1.8	2.6
0	0		7.3				4.2				11.5		

responses were largely additive (no interaction). For these studies, plants were grown to a comparable stage of growth either from rhizome pieces. Both methods of milkweed propagation gave similar results which are averaged in Figure 43. Differences in fresh weight of shoots and of roots (Table 25) were reflected in the final air dry weight of the plants (Table 26).

The relative effectiveness of 2,4-D vs. 2,4,5-T in replacing a portion of the Tordon in mixtures was examined with somewhat equivocal results (Table 27). 2,4-D seems to be more effective at the low dosage rates whereas 2,4,5-T was somewhat more effective at the highest dosage rates. In general, however the two compounds were nearly equal in their effectiveness when combined with Tordon.

Field Studies

Field studies comparing 2,4-D, 2,4,5-T and Tordon alone and in various combinations were consistent with the greenhouse observations. At an application rate of 2 lb/A in 50 gpa water, top growth was completely killed by all herbicides 6-8 weeks after treatment (Table 28).

Kill of below ground parts is essential to effective control of Common Milkweed, however. This was monitored by examining rhizome parts obtained from the treated plants (Table 29). Tordon gave complete repression of bud growth from rhizome pieces whereas 2,4,5-T was relatively ineffective in repressing bud growth even though top growth was killed by all treatments. A mixture of 0.5 lb per acre of 2,4,5-T and 1.5 lb ae per acre (3 quarts Tordon 22 K weed killer) was comparable to 4 quarts of Tordon 22 K as in the greenhouse studies. Other mixtures (1 lb 2,4,5-T plus 1 lb Tordon and 1.5 lb plus 0.5 lb) were considerably

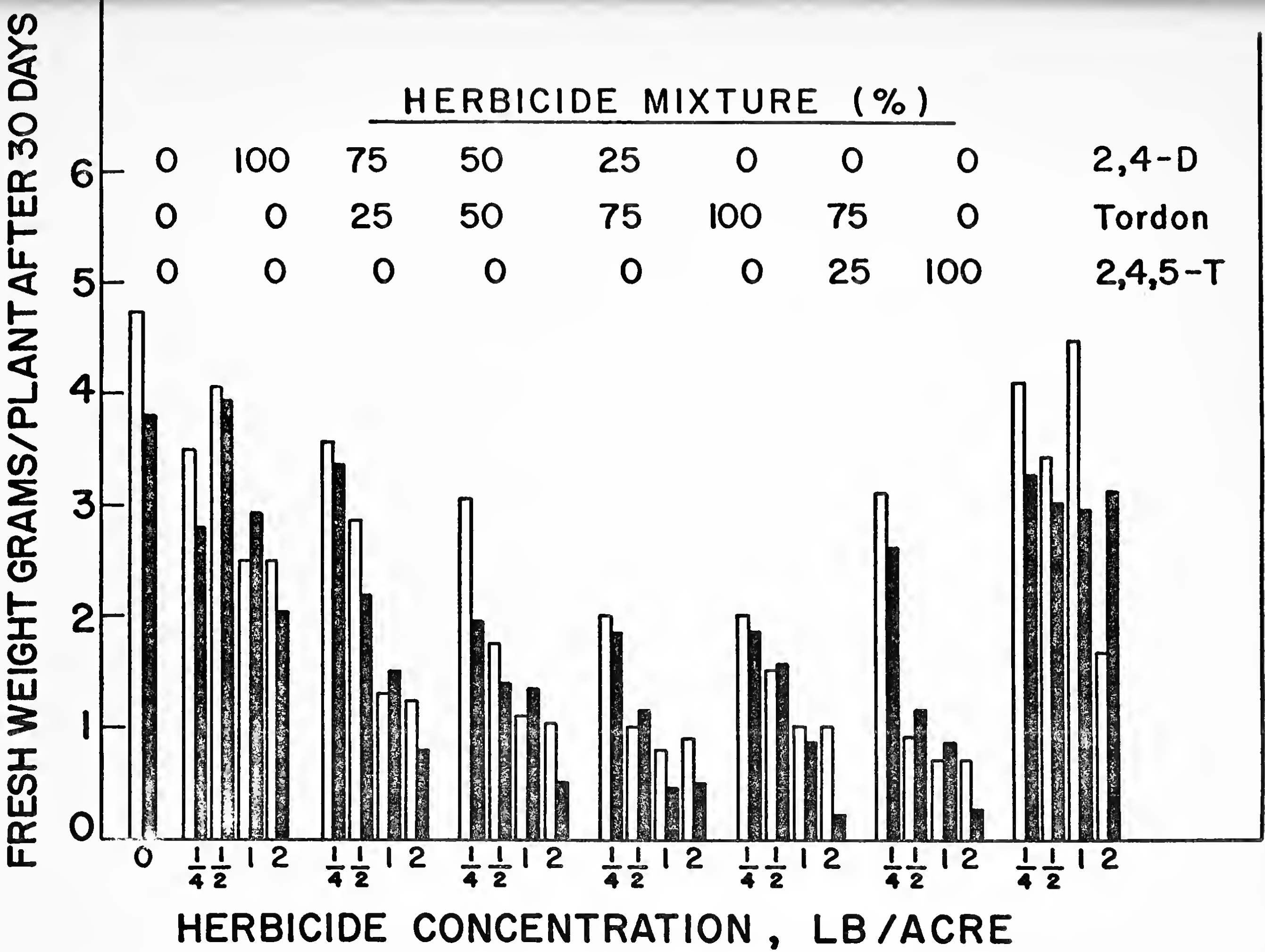


Figure 43. Effect of Tordon herbicide, butyl 2,4-D and butyl 2,4,5-T alone and in various combinations on fresh weight of milkweed plants grown from seed or rhizomes. Plants were 3 to 3.5 months old when treated. [ ] - shoots. [solid] - roots.

Table 27. Comparison of 2,4-D and 2,4,5-T as the choice of herbicide for replacement of Tordon in mixtures.

Acid equivalent percent by weight in mixture applied			Shoots				Roots				Total plant				
			0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2	lbs/A
Tordon	2,4-D	2,4,5-T	Fresh weight, grams/plant												
100	0	0	4.4	3.0	2.0	2.0	3.8	3.1	1.7	0.4	8.2	6.1	3.7	2.4	
75	25	0	4.0	2.0	1.6	1.8	3.7	2.3	0.9	1.0	7.7	4.3	2.5	2.8	
75	0	25	6.2	1.8	1.4	1.4	5.2	2.3	1.7	0.5	11.4	4.1	3.1	1.9	

Table 28. Comparison of 2,4,5-T and Tordon alone and in combination applied in 50 gpa water for control of Common Milkweed in a roadside situation near Lafayette, Indiana in 1967. Applications were made in the late bloom stage of development.

Treatment lb/A		% Top kill, weeks after treatment					
		3		6		8	
2,4,5-T	Tordon	Leaves	Stems	Leaves	Stems	Leaves	Stems
0	0	0	0	0	0	30	10
2	0	60	20	90	60	200	90
0	2	40	10	90	90	100	100
1½	½	70	10	80	70	100	100
1	1	70	30	80	80	100	100
½	1½	50	30	100	90	100	100

Table 29. The effect of 2 lb ae/A of Tordon and 2,4,5-T herbicides alone or in combination on the repression of bud growth of rhizomes collected from plants treated in the field on August 23, 1967. The rhizome systems were sampled from 1 to 8 weeks after spraying.

Acid equivalent percent by weight in mixture applied		Shoots per 15 root segments; wk after spraying						
2,4,5-T	Tordon	1 wk	2 wk	3 wk	4 wk	6 wk	8 wk	Total
0	0	8	16	10	7	7	11	59
100	0	8	6	4	15	9	4	46
75	25	1	1	1	1	3	2	9
50	50	1	1	2	7	1	1	13
25	75	0	0	0	3	0	0	3
0	100	0	0	0	0	0	0	0

more effective than 2 lb of 2,4,5-T but did not give complete repression of rhizome bud growth.

When the rhizome evaluation was terminated, rhizome pieces were removed from the pots and examined. Rhizome pieces from plants treated with Tordon herbicide alone or mixtures with 2,4,5-T were dead but rhizome pieces from control plants and plants receiving 2,4,5-T alone remained viable.

An interaction of another sort was encountered when milkweed seeds of treated plants were examined for germinability (Table 30). Germination of seeds harvested from plants treated with Tordon was similar to that of controls. However, germination of seeds from 2,4,5-T treated plants was reduced. Germinability was most effectively reduced by combinations containing 75% 2,4,5-T and 25% Tordon.

Summary

Combinations of Tordon herbicide plus 2,4-D or 2,4,5-T were studied under laboratory, greenhouse and field conditions using cucumber (Cucumus sativus) seedlings, bean (Phaseolus vulgaris) plants, and plants of common milkweed (Asclepias syriaca).

Symptom expression was slower with Tordon than with either 2,4-D or 2,4,5-T. The delayed killing action might facilitate movement of materials into below-ground parts, thereby contributing to effectiveness in the control of perennial species of broad-leaved plants such as milkweed.

Tordon was found to ultimately exert the strongest killing action in comparisons with 2,4-D or 2,4,5-T. This was especially true for milkweed which represented a 2,4-D and 2,4,5-T resistant species.

Table 30. The effect of 2 lb ae/A of Tordon and 2,4,5-T herbicides alone or in combination on the germinability of seeds collected from Milkweed plants treated in the field in late bloom stage (August 23, 1967). Seeds were collected Oct. 4, 1967, and stratified at 0 to 4°C for the lengths of time indicated. Results based on 3 replicate samples of 25 seed each.

Acid equivalent percent by weight in mixture applied		Percent germination; weeks of stratification		
2,4,5-T	Tordon	6 wk	8 wk	14 wk
0	0	56	70	94
100	0	12	28	72
75	25	4	6	6
50	50	8	24	54
25	75	48	62	82
0	100	60	72	94

The interactions between the Tordon and 2,4-D or 2,4,5-T were found to be additive (independent) or competitive depending upon the plant material, rate of application and the time after treatment when the evaluations were made. There was no evidence of true synergism.

Certain mixtures were more active than would have been predicted on the basis of an equal competition of the two herbicides for the same active sites in the plant (apparent synergism). With primary roots of cucumber seedlings, growth inhibitions by 2,4-D did not appear to be influenced by the presence of Tordon in amounts including up to 75% of the total growth regulator mixture. With bean and milkweed, the effectiveness of treatments was enhanced by partial replacement (25%) of the 2,4-D or 2,4,5-T by Tordon. The relative effectiveness of Tordon in such mixtures was inversely related to the total amount of herbicide applied.

With all species tested, at least 25% of the Tordon at a given treatment rate was replacable by 2,4-D or 2,4,5-T without a significant decline in overall herbicidal effectiveness as compared to Tordon alone. This arises as a natural consequence of the logarithmic dose-response curve for plants treated with two different auxin herbicides in the absence of equal competition for receptor sites and is not true synergism.

Application of 2,4-D or 2,4,5-T + Tordon mixtures to Common Milkweed Plants in the late bloom stage of development (August 15-30) gave best results, in terms of control of below ground plant parts. This is the time of year when the plants normally move organic materials into the below-ground storage parts. An unfortunate aspect of this treatment is

that viable seed is still produced. 2,4,5-T applied at the same time reduced seed production but gave incomplete kill of existing rhizomes.

A combination treatment of 1½ lb/A Tordon + ½ lb/A 2,4-D or 2,4,5-T applied in sufficient water to thoroughly wet the plants (approximately 50 gpa) has given consistent and adequate control of Common Milkweed to permit use of this treatment for Milkweed irradication when applied at late bloom stage.

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V. RECOMMENDATIONS

Milkweed Control

$1\frac{1}{2}$ lb/A Tordon herbicide + $\frac{1}{2}$ lb/A of either 2,4-D or 2,4,5-T (ester or amine salt) applied at the late bloom stage of development (mid-August). This combination herbicide treatment gives complete control of existing Milkweed plants and prevents regrowth.

Wild Garlic

Treatments beginning in mid-March, when the plants are about 4 inches high, are most effective. Plants first treated with 1 lb/A CIPC. After growth of about 2 inches has occured (mid-April), the foliage is bruised to mechanically rupture the cuticle. For spot treatment, flattening the plants with a lawn rake is effective. For larger areas, a corrugated roller might be used. Immediately following the beating or rolling treatment, 2,4-D is applied at a rate of 1-2 lb/A. This combination treatment gives complete control of existing Wild Garlic plants, including primary bulbs, and at least 50% reduction in numbers of secondary bulblets.